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CONTENTS

Colin Maher: Soil Conservation in Kenya Colony. Pt. II. Soil Conservation in Practice: Organization and Legislation: Present Position and Outlook. With Plates 10–13 233

John Hancock: Grazing Habits of Dairy Cows in New Zealand 249

R. O. Davies, W. E. J. Milton, and J. R. Lloyd: Pasture Productivity in Mid-Wales. Pt. II. Botanical Changes in the Experimental Plots: Palatability and 'Efficiency' of the Swards. With Plate 14 264

D. B. Murray: Photoperiodism in Rice in Trinidad with reference to a Second Crop 271

R. G. H. Wilshaw: Agronomic and Breeding Research on Rice, Oil-palms, and Cacao in Malaya. Pt. II. Oil-palms and Cacao 276

J. Procter and A. H. Lewis: An Experiment on the Productivity of Leys cut for Hay 281

W. H. Pearsall: The Investigation of Wet Soils and its Agricultural Implications 289

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SOIL CONSERVATION IN KENYA COLONY

Pt. II. SOIL CONSERVATION IN PRACTICE: ORGANIZATION AND LEGISLATION: PRESENT POSITION AND OUTLOOK

COLIN MAHER

(*Senior Soil Conservation Officer, Department of Agriculture, Kenya Colony*)

WITH PLATES 10-13

Soil Conservation in the Arable Areas

Planning on the farm.—Although the addition of humus is of such overweening importance that this question has been dealt with first (Pt. I), in point of time the conservation engineering framework in the field comes first. Natural drainage-lines have to be selected which will be left under grass in order to take the water from diversion ditches or terraces, or the positions of artificially constructed drainage-channels have to be selected. The situation of farm roads has to be decided to conform with the water-disposal system, and to give access to all fields and buildings on the farm with ease and without causing more erosion. Subdivisions of fields will usually be made at right angles to contours and main fence lines will be aligned along contours as nearly as possible.

Diversion or cut-off ditches are placed wherever it is necessary to prevent surplus water running on to a field from above, whether from hill-sides, buildings, yards, or roads. These ditches are usually grassed so as to carry water at velocities of 3 to 6 or 7 ft. per second without the bottom of the channel being liable to scour. The grades are gentle, increasing with the length of the ditch, so as to carry the cumulative quantity of water at uniform or slightly increasing velocities in order to prevent silting of the ditches. These ditches usually have grades of from 0·1 to 1 per cent. and depths of 18 in. to 3 ft. The capacities of the channels are calculated on hydraulic principles.

Within the field, the type of measure used will depend on the soil, the slope and the value of the land, and the kind of farming which is to be carried out. The measure selected will also depend on the availability of machinery, and sometimes on the necessity to use the cheapest method compatible with reasonably good control of erosion, though there is a limit to the extent to which efficiency can be sacrificed for economy.

Strip-cropping.—First of all there is strip-cropping with widths of arable cultivation alternating with strips of permanent grass or of grass leys. It is hoped to encourage the use of the grass strips not only for dry-season grazing when the crops are off, but for grass silage, hay, or wet-season grazing by means of electric fences. 'Field stripping', in which strips only approximate very roughly to the contour and may deviate considerably from it, is not a satisfactory method of erosion control in Kenya, where heavy storms have to be dealt with. As a general guide the following intervals were suggested for the Soil Conservation Service [hereinafter designated S.C.S.]:

Slope (*per cent.*)	*Arable* (*ft.*)	*Grass* (*ft.*)	*Slope* (*per cent.*)	*Arable* (*ft.*)	*Grass* (*ft.*)
0 to 2	100	40	6 to 8	60	40
2 to 4	80	40	Over 8	40	40
4 to 6	70	40			

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On steep hill-sides with over 15 per cent. slope, the amount of arable (each strip not wider than 30 or 40 ft.) should not occupy more than about a third of the total area available, and it is recommended that the system should be strengthened by the use of diversion ditches.

The success of this system depends on careful contour ploughing and cultivation. Any irregularities in the contour should be taken up by increasing the width of the grass strips. Further, the arable areas should be cropped for only 3 years, or 2 years on the steeper slopes or more erodible soils, before restoring grass. It would be possible to work a system in which half the arable land was underseeded with grass each year, and, after the main rains had fallen, a corresponding portion of the grass strips broken up to prepare for a crop in the following year. Close-growing crops should be planted on at least part of the area. Needless to say, grass strips cannot dispose of all surplus run-off. They can merely spread the run-off, reduce its velocity, and filter off some of the soil carried in the run-off.

Terracing.—Next is a system of broad base terraces with channels having a V-shaped section. These are similar to those used in the SE. states of the U.S.A., and are about 15–20 ft. wide, 15–20 in. deep with a cross-section in the channel of 8–10 sq. ft. or more. Terraces, in effect, subdivide a field into a number of narrow independent catchment areas, so reducing the length of flow of run-off water to about 50–100 ft. down the slope, and its erosive potentialities.

The usual vertical intervals in use are as follows:

Average slope	*Vertical interval in ft.*
Under 1 per cent.	1·0
Over 1 „	2·0
2 „	2·5

Up to 12 per cent. add 0·25 ft. to the vertical interval for every extra 1 per cent. in the slope.

These terraces may be left under grass or kept cultivated. If left under grass they may or may not have a filter strip of grass 25 ft. wide left just above the channel. In the latter case an additional 25 ft. is usually added to the horizontal interval between terraces. The usual grade is as follows:

	Fall		*Fall*
0 to 300 ft.	½ in. in 100 ft.	900 to 1,200 ft.	3 in. in 100 ft.
300 to 600 ft.	1 „ „ „	1,200 to 1,500 ft.	4 „ „ „
600 to 900 ft.	2 „ „ „		

Sometimes, however, the grade is started at 2 in. in 100 ft. If the channels are to be left under grass, grades may be used as follows:

	Fall
0 to 300 ft.	4 in. per 100 ft.
300 to 700 ft.	5 „ „ „
700 to 1,100 ft.	6 „ „ „
1,100 to 1,500 ft.	9 „ „ „

In some districts where the rainfall is heavy and weed-growth is rapid it has been found desirable to increase grades to 2 in., 3 in., 4 in., 5 in., and

6 in. per 100 ft. in successive 300-ft. stretches, or even to use the grades shown above for terraces under grass.

Various devices combining strip-cropping with diversion ditches are also under trial. On the S.C.S. Farm at Kitale one field is protected by diversion ditches, each with a capacity of 30 sq. ft., at intervals of 100 yds. Half-way between each ditch is a contour fence, and alternate 100-yd. strips between fences are planted to grass leys, which are alternated with the arable strips every 2 or 3 years. Thus there are never more than 50 yds. of arable cultivation above or below a diversion ditch, and the water either runs off 50 yds. of grass on to the arable, or off 50 yds. of arable through 50 yds. of grassland into the diversion ditch. The success of this scheme will depend on maintaining sufficient humus in the soil to secure maximum absorption of the rainfall.

On the richer soils and on farms where potential arable land is limited, orthodox broad base terraces with flat channels are made of the type used in the Midwest of the U.S.A. [1]. These terraces are usually 24–30 ft. wide with a cross-section in the channel of at least 10–12 sq. ft. The machine generally used by the S.C.S. is a No. 2 Caterpillar Terracer, drawn by a D. 6 Caterpillar Diesel Tractor or similar tractor. Also used are No. 22 and No. 1 Caterpillar Terracers, which are drawn by farm tractors of smaller horse-power or by oxen. Wheel tractors are not so suitable owing to the tendency to wheel-spin in the loose earth piled up on the bank. It has been found convenient to fill in gullies and washes on the lines of the terraces and to level termite mounds and other irregularities by means of a Caterpillar D. 7 Tractor and Angledozer, or by a Traxcavator before building the terraces. Curves are eased out before construction in order to facilitate ploughing, but all terraces are checked again and channels and banks brought to grade by machine (small carry-all scrapers have been found useful) or by hand-labour before the job is considered completed. The limit of slopes on which flat-bottomed channels can be built is considered to be 8 per cent. The wider terraces are required on wheat fields where combines are to be used, so if V-channels have to be made on steeper slopes the terrace banks must be left under grass or planted to some other crop. Alternatively, the wheat on the banks could be cut by hand or possibly by autoscythe.

The cost of the larger terraces is about 304*s.* a mile (including machine and African labour costs but exclusive of European supervision and overheads), or about 38*s.* an acre at 8 acres to the mile. The V-channel terraces are cheaper at 96*s.* a mile or 16*s.* an acre at say 6 acres to the mile. (The acreage per mile varies with the slope from 5 to 24.)

Wherever terraces are introduced into a farming system it is necessary to conduct all cultural operations on the contour. Particularly is it necessary to plough the terraces according to one of the methods recommended by the S.C.S. [2]. It has been found that ploughs, with hydraulic lifts, attached directly to the tractor are most satisfactory for ploughing terraces as they are not subject to side-slip. Some 'trailed' ploughs pulled by small farm-tractors have also been doing good work even on steep slopes up to 18 per cent. although 12 per cent. is the maximum slope that is normally recommeneded for terracing.

Contour ploughing is indeed a *sine qua non* of the maintenance of terraces. On easy slopes with absorbent soils a few conservative farmers continue to farm across their terraces without causing great damage. Generally, however, it is highly desirable that all planting and cultivation shall be done along the contour. Planter and cultivator marks, harrow furrows, and wheel tracks then all help to conserve water, assisting storage in the soil of water which the crop may urgently need later in the season, at the same time the rush of water down the slope, carrying valuable soil, is retarded. Large quantities of top soil have often been washed down fields, filling up terrace channels, merely by planting, or using a tooth-harrow, up and down the slope just before a heavy rainstorm.

Bench terracing.—Where high-priced crops like fruit and vegetables are to be grown, there is a case for building regular bench terraces, somewhat like those used in rice-growing countries, or those made in Peru by the Incas. Terraces supported by rough stone are rarely made even in the native reserves. The S.C.S. has built a few hundred acres of bench terraces by angledozer and terracer for irrigated gardens or orchards. The height of the 'risers' or the vertical intervals of the terraces is usually limited to 3 or 4 ft., the banks with 1:1 slopes being protected by grass. If the terraces are merely for 'erosion' control they are given a backward tilt of 1 per cent. towards the hill into drains cut at the foot of each bank; if they are needed for irrigation, they are made level across their width with a longitudinal grade of 1:150 or 1:200. The cost per acre of such work on a slope of 25–30 per cent. is likely to be at least £25–£30 today. If hand-labour is used about 300 man-days are required per acre; so the cost will be approximately the same if an inclusive cost of 2*s.* per man is accepted.

The foregoing is a rapid summary of some of the main points of soil conservation on the arable areas. Methods are used for establishing a protective cover in drainage-ways and diversion ditches which are similar to those used by the S.C.S. in the U.S.A.

Erosion Problems in Plantation Areas

Tea.—Heavy rain is experienced from time to time in the tea areas of the Kericho and Nandi districts. Tea plantations are very liable to suffer erosion during the first 6 or 7 years after planting, before the tea bushes have formed a complete canopy, and again after pruning—though the prunings, if used as a mulch, should then give a good protection to the soil. A series of soil conservation measures was proposed by the S.C.S., accepted by the Kenya Tea Growers Association, and formally approved early in 1949 by the Director of Agriculture as a basis for legal sanctions where necessary. These measures include, on slopes under 16 per cent., the use of variable-grade terrace banks; the planting of tea as far as possible in lines across the slope; the placing of weeds and pruning in rows as nearly as possible on the contour. Alternative to terracing, the tea may be contour planted on lines parallel to master contours. On slopes above 16 per cent. contour planting is insisted upon; on slopes between 16 per cent. and 24 per cent. bench terraces are to be developed on individual rows during weeding operations; on slopes between 24 per

cent. and 30 or 35 per cent. regular bench terracing is considered necessary. General measures advised include in-filling all blank spaces, the use of cover crops and bush cover crops like *Tephrosia vogelii* in young tea, or selective weeding. Contour planting of tea on an experimental scale is requested on slopes *below* 16 per cent., to compare this system with customary square or triangular planting.

Wattle.—Black Wattle (*Acacia mollissima* var. *utilissima*) has been a notorious cause of erosion, causing vivid red scars on steep hill-sides in the Kikuyu Reserves owing to the lack of a ground-cover underneath the trees. In part it must be admitted that this is due to the trampling, browsing, and grazing in the plantations of cattle, sheep, and goats seeking shade or food: this results in the natural mulch of twigs, leaves, and seed-pods being reduced to a powder, which is washed down the slopes by the torrential rains, together with the top soil. With the expansion of the activities near Eldoret in the European areas of Kenya of the East African Tanning Extract Co. (a subsidiary of the Forestal Lands Company and a sister company to the Natal Wattle Extract Co.), which proposes to treat the bark from 25,000 acres and ultimately from 50,000 acres of wattle in the Uasin Gishu district, the question of the most suitable measures for soil conservation has become more pressing and has been under review by the S.C.S. since 1945.

One of the most important points in connexion with the cultivation of wattle is the effect on the soil of periodic burnings, to procure germination of the hard seed lying on the ground and regeneration of a plantation, after the bark has been stripped and the trees felled. The intensity of the burn varies according as the trunks and branches have been removed for firewood, or the brush-wood only is burnt; and whether the burning is carried out while the ground is dry or damp. The officers of the East African Tanning Extract Co. think that the best establishment of new trees is obtained after the fiercest burn. Such a burn, of course, destroys some part of the organic matter in the soil and even consumes or carbonizes the seeds lying underneath the burnt timber of the trunks and larger branches. However, plenty of seeds germinate just outside the zone where the heat is most intense along the tree lines. In Natal only a 6-in. strip covered by twigs piled about 3 in. high is burnt with a blow-lamp at 10 or 12 ft. intervals under recommended modern practice. In Kenya paraffin flame-throwers have been employed to burn grass and brush-wood along the future lines of trees.

A possibility not yet fully investigated but potentially of great promise is to regenerate plantations by ratooning. New shoots soon grow from stumps if the bark has been left at the base of the old trees, and these shoots appear to exceed seedlings in rapidity of growth. If there is no major objection to this method of restoration of a plantation it would not only be very cheap, as the thinning of suckers would be almost all the work required, but it would preserve a cover on the ground and avoid the loss of organic matter caused by burning. It does not seem, incidentally, that a light burn has much effect on the soil, but such a burn may not be entirely satisfactory in depressing temporarily the running 'couch'

grasses (*Cynodon* spp. and especially *Digitaria scalarum*), which rapidly infest the land after a wattle plantation is felled in Kenya; nor does a light burn always produce a sufficient germination of wattle seeds.

The period of erosion danger begins when the bare ground is exposed just before planting a new wattle plantation; the next period from 4 to 6 years later after the closed overhead canopy has caused the ground cover to die or become negligible in amount. In the interim period the land is cleaned only for 18 in. on either side of the rows of seedling trees, the remaining 6 or 7 ft. between lines being covered with grass or weeds. However, the not improbable popularization of clean weeding with rotary hoes whilst encouraging more rapid growth of the trees would increase the erosion risk in the early life of the trees. The present general proposals are that: (i) diversion ditches shall be built on the top side of any plantation wherever there is any danger of run-off entering from above; (ii) on slopes below 3 per cent., the trees shall be planted in rows as near the contour as is practicable. Long slopes, even on gentle grades, may have to be protected by occasional diversion ditches; (iii) on slopes above 3 per cent., diversion ditches shall be made which shall also be used as master contours to serve as guides for planting. The frequency of these ditches will be governed by the steepness of the slope and by the necessity for introducing a new master contour if the tree-lines drawn parallel to a contour start to deviate by more than 1 per cent. grade from the level contour above for more than 50 yds.; (iv) fire-breaks of ploughed strips around stretches of the plantations must be interrupted every 50 yds. or so by short diversion banks on ½ or 1 per cent. grades where the fire-breaks run on erodible grades.

In general, soil-conservation measures appropriate to wattle have to be selected to accord with the current sylvicultural practices; and there is a wide and unexplored field for research regarding the effect on the soil and crop of burning as a means of regeneration, the effect of spacing, clean weeding, and various other practices all of which must be considered in connexion with the prevention of erosion.

Sisal.—Unfortunately no carefully controlled experiments have been made in Kenya Colony to provide reliable figures for enabling a comparison to be drawn between the loss of the soil and of run-off water from plantations of sisal planted on the contour and from sisal planted up and down hill. A loss of over 20 tons of top soil per acre was, however, measured at the High Level Sisal Research Station at Thika, following a fall of 4½ in. in a night, from a plot of about 0·3 acres soon after it had been planted with sisal rows running up and down hill. The slope was 14 per cent. and the plot was 144 ft. long.

It seems probable that little erosion occurs in sisal plantations if the rows are planted on a grade not steeper than 1 or 2 per cent. Obviously, the nearer the rows are planted to the true contour the less is likely to be the loss of water by run-off. Although sisal (*Agave utilissima* var. *rigida*) is drought-resistant, if there is a shortage of water for the plants the leaves become smaller and the yield of fibre is reduced.

Sisal is generally planted in rows about 12–14 ft. apart and 2½–3 ft. between plants. In order to facilitate tractor cultivation by disk harrows,

a spacing of 13 ft. between rows is now recommended, followed by a double row 3 ft. apart. In the double row there is a distance of 2 ft. 9 in. between plants in a row, the plants in the two rows being 'staggered'. The usual practice is to keep plantations for 10–15 years. As the plants flower ('pole') and die they are removed, their places being taken by young suckers. Towards the end of the cycle a plantation is usually covered not only by tall grass such as *Hyparrhenia* spp. but by young *Acacia* thorns, *Combretum* spp., and other young trees and bushes.

The regeneration of grass and bush gives an admirable cover to the soil, but the sisal leaves tend to become reduced in size and yellowish, due to the competition of the natural vegetation for nitrogen and moisture. At this stage yields are poor. The present recommendation of the Agricultural Officer in charge of Sisal Research at Thika is that an 8-year cycle should be adopted during which the crop will be clean-weeded for 3 or 4 years. This will result in exposing the soil to the baneful effects of sun, rain, and wind for nearly one-half of the time, instead of the 20–25 per cent. of the time which is the result of present methods. As usually happens, more efficient methods of production (and the possibility in this instance of obtaining yields of fibre which may be three or four times as great as under the old system) will greatly intensify the risks of serious erosion.

On many plantations sisal has been planted on slopes as steep as 20–25 per cent. or more; severe erosion has sometimes occurred, increased by losses resulting from the use of tractor-drawn 'one-way disks' or 'harrow-ploughs'. Plants growing on eroded subsoil are notably poorer in appearance and in rate of growth.

Soil and nutrient losses could be reduced by a greater use of factory wastes as a mulch in the fields, a practice that is being followed to some extent by a few planters.

The S.C.S. in Kenya is advising the adoption of contour planting on the basis of parallel planting to master contours on which level terrace banks would be made. Short rows due to irregularity of the ground would be run into the terrace next below. The frequency of the master contours generally would be determined by the necessity for re-alining the rows on a true contour as soon as rows below a 'master contour' run on a grade of 1 per cent. or more for a distance greater than 150 ft.

The length of the level terrace banks usually would be limited to 360 ft., because feeder roads or traces are required at this distance in order to keep the 'carry' of leaf to a maximum of 60 yds. The general lay-out of soil conservation measures in a sisal plantation is complicated by the need of incorporating the alinement of a narrow-gauge rail-track for trucks carrying leaf to the factory, main and feeder roads to the rail-track, and channels for water disposal at the ends of the terraces where they abut upon the roads. The problem is not simple, but it is believed that a system can be worked out which will be feasible and economic and will result ultimately in giving more profitable returns of leaf, without detriment to the long-term resources of the soils of the sisal plantations.

Coffee.—Coffee soil is very subject to erosion. Abandoned coffee plantations have been seen in the Songhor district of the Nyanza Province

where the coffee plants are standing, with exposed roots like stilts, on high ridges left between eroded gullies 3 ft. deep, which run down between every row. In the main coffee areas near Nairobi, erosion and soil deterioration, though not spectacular in the way just mentioned, has been serious enough to be considered responsible at least in part for a fall-off in yield. Streams in the coffee districts do indeed flow thick with chocolate-coloured mud; but this is due to some extent to the custom of coffee-planters giving gardens to their resident labourers on the steep slopes running down to the streams as being virtually unusable for any other purpose.

The chocolate-red earths (volcanic loams) of the coffee areas, having high proportions of colloidal clay, fortunately have a high degree of resistance to erosion. Mulching, either complete or mulching of half-rows or of alternate rows, is the erosion-control measure in coffee *par excellence*, as well as being a valuable means of conserving moisture and of adding humus to the soil. This measure is practised extensively with banana leaves and Elephant grass (*Pennisetum purpureum*) by the Wachagga on Kilimanjaro and by the Bagishu coffee-growers on Mount Elgon; it has been advocated officially for many years to European planters by the Departments of Agriculture in East Africa. The chief difficulty is that 1 or 2 acres of Elephant grass, or about 3–5 of natural veldt grass, are needed to mulch 1 acre of coffee, and it is very difficult for the average coffee-grower to obtain anything like the amount of grass which he requires. Clean weeding is necessary to avoid water-loss by transpiration of the weeds during the dry season; but the removal of all weeds during the rainy period is not only liable to increase sheet erosion but, according to Pereira, to reduce pore-space in the soil by destroying the soil crumbs. Cover-cropping has never become an established and successful practice in Kenya, largely owing to the danger of causing unfavourable water-relationships for the crop.

Campaigns have been carried out from time to time during the past 20 years to induce the coffee-planters to carry out narrow base terracing in their coffee. This practice in fact is carried out on many plantations today instead of the rather old-fashioned system of silt-pitting. In most cases, however, the size of bank is not adequate to deal with the maximum run-off that is likely to occur. A major difficulty is that, practically without exception, the plantations have been planted with what is, to the conservationist, irritating mathematical precision and with complete disregard of contours. Any terraces made in old coffee have to be dug by hand, if trees are not to be removed. As labour is increasingly expensive and more and more difficult to obtain, there is a tendency to rely on mechanical cultivation with light tractors. The passage of these implements up and down and across the coffee-rows naturally results in partial demolition of all contour terraces, which have to be made up again by hand.

Officers of the S.C.S. have examined this question in collaboration with officers of the Coffee Services of the Department of Agriculture. Methods of establishing new plantings on the contour have been prescribed, together with various types of terrace banks, and possibilities

have been considered of building small terraces through old coffee, by using small tractors, with the removal of as few trees as possible. Proposals have also been made for establishing experiments to measure loss of run-off water and silt on typical slopes in coffee plantations.

In areas of low rainfall 'box-ridging' (i.e. building up a low ridge with soil and weeds, so as to enclose each tree within a complete four-sided ridge) is sometimes practised with benefit and success; but the use of this method is limited to gentle slopes on absorbent soils with a low rainfall of 30 in. a year or rather less.

Pyrethrum.—In the Nakuru district most farmers who grow pyrethrum are said to have made some effort to prevent erosion. There are 6,000 acres of the crop in this area. Some have used narrow base terraces and some have used grassed banks, but on many farms the anti-erosion measures have not always been entirely satisfactory even if the farmers often consider them to be so. In many instances the banks were put in after the pyrethrum had been planted on a check-row system. Cultivation has been continued across the grass banks or terraces, often by a small scuffler pulled by a donkey. The S.C.S. in this district recommends narrow base terraces, on a grade, at full vertical intervals. The pyrethrum frequently is ploughed out after a period of 3 to 5 years and the field is then planted to wheat. If the terraces are not too close together the farmer usually will leave them intact and plant his wheat in between; otherwise it is more than likely that he will plough out all the terraces when he prepares the land for wheat.

Perhaps the most important factor affecting soil conservation in pyrethrum is contour planting. A spacing recommended is 3 ft. apart between rows, with plants 1 ft. apart in the rows. Sometimes a double row 1 ft. apart is planted followed by a 3 ft. spacing, and so on. When the plants grow large they meet and form a continuous contour line, and then very little erosion results; the terraces become merely additional insurances, as most of the run-off water and eroded soil is retained by these continuous lines of plants. Where the pyrethrum has *not* been planted on the contour, it has sometimes been necessary to remove silt from the terrace channels five or six times in the year.

The Senior Assistant Soil Conservation Officer in the Nakuru district, Mr. C. F. Newton, states that, generally speaking, erosion in pyrethrum is serious, and though it is not necessarily spectacular it is insidious. This crop has to be kept clean of weeds for a good yield of flowers to be obtained. Some growers indeed prefer to obtain a smaller return and avoid having absolutely bare ground between the rows. As a rule, however, the continual cultivation and frequent trampling by labourers weeding or picking the crop, pulverizes the soil, so that it is particularly susceptible to erosion.

The Assistant Soil Conservation Officer responsible for duties of inspection on farms in the Laikipia district, where there are over 3,000 acres of pyrethrum, is even less optimistic. Apart from a few farms on which terracing has been carried out, there is little evidence of any real effort at erosion control, he says. Gully erosion is not uncommon on pyrethrum fields in the area, but the main problem is sheet erosion. The

plantations of pyrethrum in this district invariably present a scoured appearance especially where planting is done in straight parallel rows which frequently are alined on an excessive grade. Both broad and narrow base terraces are used to reduce erosion. Another measure finding some favour is the use of ridges approximately on the contour, a row being planted on each ridge. It is questionable, says the Inspector, if this technique will be effective in controlling erosion on the steeper slopes in the higher rainfall areas.

Theoretically, the use of wheat straw as a mulch might be advantageous, as it should benefit the flowers in the drier spells and would prevent sheet erosion. A drawback is the tendency for Kikuyu grass, which is indigenous at these high altitudes, to become established amongst a mulch of straw or grass.

Incidental disadvantages of this profitable Kenya crop are its demand for a large quantity of firewood for use in the driers, and the need for large numbers of labourers and their families for weeding and picking. Both these factors lead to denudation of forest land and, too frequently, to the spoliation of steep valley-sides, formerly under a good protective cover of forest trees and bush.

Organization of Soil Conservation Work in the European Areas

The S.C.S. has six District Headquarters in the European areas of Kenya Colony. There are three Dam Construction Units operating heavy tractors, carry-all scrapers, and angledozers; a Dam Survey Unit consisting of one engineer and African staff; and a Senior Soil Conservation Engineer stationed at Nakuru where the General Headquarters of the Service are ultimately to be situated, with one Soil Conservation Engineer assisting him. At present the General Headquarters with a Senior Soil Conservation Officer in charge are at Kitale near Mount Elgon and inconveniently at the north-eastern tip of the European areas. The district headquarters are at Kitale for the Trans Nzoia district, Eldoret for the Uasin Gishu district, Nakuru for the Nakuru district, Thomson's Falls for the Laikipia–Naivasha districts, at Ruiru for the Nairobi areas, and at Lumbwa for the Nyanza Province European districts in or near the Lake Basin. The two latter are one-man stations operating only one Government tractor, but the former stations each have two field officers (three at Nakuru) with three D. 6 Caterpillar or T.D. 14 International tractors for terracing. In addition there is a D. 7 Caterpillar tractor for levelling termite mounds or doing other heavy earth-moving work preparatory to terracing at Kitale, Eldoret, and Thomson's Falls. In the Nakuru district a Traxcavator (a small mechanical shovel mounted on a D. 4 Caterpillar tractor) has been found more convenient. Workshops for repair of tractors and machines with European and African mechanics are established at Kitale and Nakuru. All of the Dam Construction Units are self-contained with a mobile workshop and other equipment to permit of repairs being done in the bush when necessary.

Assistant Soil Conservation Officers in charge of S.C.S. districts cooperate with district Agricultural Officers in preparing programmes in

order of priority, economy of movement being an important factor. These officers, assisted by engineers when necessary, also work together in preparing comprehensive long-term farm plans, though the degree to which this is carried out varies from district to district. Nakuru with a highly co-operative farming community leads in this development. One of the main difficulties is in securing a contour map of each farm to be planned. The Colonial Survey, which has been partly completed by air, unfortunately is not on a scale large enough to be of much value for detailed planning. In some districts an S.C.S. African 'leveller', normally educated up to School Certificate standard or nearly up to it, carries out a contour survey by plane table to the required accuracy of under 5 per cent. error. A scale of 1:5,000 or 1:2,500 is used.

The tractors and machinery of the S.C.S. are entirely operated by African staff under European supervision, and the bulk of the setting out of terrace and ditch lines is done by secondary-educated trained Africans. Farmers are charged only for actual cost of operating the machinery and the cost of the African staff. Other costs and overheads such as European supervision, transport, and other charges are not paid by the farmer, who in effect receives an unseen subsidy of from 30 to 60 per cent. The cost of dams is, however, recovered in full.

Some conservation work is also carried out by farmers without the advice or assistance of the S.C.S., but farms in Kenya Colony are large, most of them being of a thousand acres or more; and the average farmer usually lacks the time, equipment, or knowledge to make a success of the construction of anti-erosion works. There are, of course, a few notable exceptions. Soil conservation to be successful generally needs a technique that is developed only after years of training and experience. A job that is half-done or inefficiently done may or may not increase erosion: it will almost certainly transmute insidious sheet erosion into spectacular gully erosion. Further, most farmers benefit from a discussion with experienced officers of the Department of Agriculture relating to the combination of agronomic practice and soil conservation methods that is most suitable for the farm and the farmer. Very often the farmer with goodwill and initiative may plunge into troubles which with a little more knowledge or prior consultation he might have escaped.

Inspection and Legislation

In addition to the executive Assistant Soil Conservation Officers who are stationed in each area there is an Assistant Soil Conservation Officer-Inspector in each of the districts mentioned, except in the Nairobi area where at present one officer has the double role. These inspectors are administratively responsible to district Agricultural Officers and report upon the maintenance of anti-erosion works, and upon areas which need special action, such as terracing, closing to cultivation, limiting the rate of stocking, or other measures in the interests of the protection of the soil and water-supplies of the Colony. The Inspectors control numbers of African River Scouts who patrol the river valleys and prevent cultivation in the vicinity of the stream banks, report practices likely to cause pollution or diminution of the water-supplies and kindred matters.

Action of a positive nature can be taken by the Director of Agriculture on the advice of his field officers, under the Land and Water Preservation Ordinance, 1943, and the various Rules thereto. These Rules, amongst other powers, enable the Director to order a farmer to carry out work for the prevention of soil erosion or to abstain from practices detrimental to the cause of soil conservation. Breaches of the Rules or of an Order made under the Rules render a farmer, on conviction by the civil courts, liable to penalties up to a fine of £100, or six months' imprisonment, or both such fine and imprisonment. If necessary the Director or his representatives can enter upon land to carry out work on behalf of the owner or occupier, and can recover the cost of the work by means of a loan taken out with the Land and Agricultural Bank of Kenya, repayable over 10 years and bearing interest at $3\frac{1}{2}$ per cent. Loans for a similar purpose can be taken out by the farmer *voluntarily*, and these are repayable over 30 years. The more drastic powers given to the Director of Agriculture by this Ordinance and Rules are rarely used in practice. On the other hand there is usually an outstanding programme of 3 or 4 years' work requested voluntarily by farmers in every district in which the S.C.S. works.

There is an Appeal Board of three persons constituted under the Land and Water Preservation Ordinance. This Board has never been called upon during the 10 years during which the Ordinance and the preceding Land and Water Preservation Ordinance, 1940, have been on the statute book. These Ordinances have been of great value to the Colony and have been actively implemented as far as staff permitted. There is a Control of Grass Fires Ordinance, 1941, which 'provides for the control of grass fires', but although it has far-reaching provisions it has only been a partial success in reducing the annual grass and bush fires that rage devastatingly in many parts of the Colony every dry season.

A Bill with even wider scope than the Land and Water Preservation Ordinance, 1943, and known as the Agricultural Bill is under consideration. This bill was criticized strongly by sections of the European farming community, and it was to be re-drafted and again circulated for discussion in the farming districts. Whilst making money available to the farmer on advantageous terms, the Bill gave powers to Government to exercise power through local committees in penalizing the bad farmers in a manner similar to that which was possible by war-time legislation in England.

Soil Conservation in the European Settled Areas: Present Position and Outlook

Looking through an old file I noticed that Sir John Russell first asked me to write this article in 1938, before I had been in charge of the embryo Soil Conservation Service for a year. I saw also that a Provincial Commissioner in the same year criticized one of my reports on one of the Native Reserves in the following surprising words: 'It is, however, suggested that his reports would be far easier to assimilate if he did not discuss at length subjects only indirectly connected with soil conservation which are the concern of other Departments, e.g. land tenure, the need for the natives to eat more meat, improved housing, etc., and confined himself solely to the problems of soil erosion and soil conservation.'

Understanding of the relationships of soil conservation has made some strides since then, it must be admitted. Likewise on the constructive side progress has been made both in the European and native areas. The S.C.S. in this Colony is now terracing with broad base terraces between 9,000 and 10,000 acres a year. It should be possible to raise this output to 20,000 acres annually following the acquisition of additional tractors during the past few months. These statistics take no account of the considerable mileage of drainage-ways, diversion ditches and roads which are also built every year in connexion with farm conservation schemes.

The desirability of employing some means of protecting their lands against soil erosion is understood today by most farmers, and many are enthusiastic converts to conservation. A great many officials and laymen now appreciate more clearly than the Provincial Commissioner of twelve years ago that soil erosion is the outward and visible sign of a material amount of disharmony on the agronomic, social, and economic planes. Quite a number of farmers see the need for rationalizing their farming activities on land-use and economic-planning lines. It is less clearly recognized in government circles that substantial progress in this direction cannot be made if no more staff is available for the job than was visualized as necessary even 5 or 6 years ago, when soil conservation schemes were being framed as a basis for an appeal to touch the pocket of a benevolent 'Home Government'.

Failure not only to consolidate soil conservation gains—and even a lay visitor arriving by air cannot but notice the tortuous contour lines streaking the farmlands in almost every district—but to speed up the rate at which planning and executive soil conservation work can be carried out may have disastrous results on the economy and social framework of the Colony. There are several reasons for this. The needs of Kenya Colony and neighbouring territories for cereals during the war period have not diminished; on the contrary there is much land in southern, eastern, and central Africa that is not self-sufficient for foodstuffs. In Kenya there are areas that have become over-populated or have deteriorated, or suffer from an erratic and mediocre rainfall, or where all these factors exacerbate an already uncertain situation. These have to be supplied with foodstuffs from more fortunate areas: and the local population is not always able to pay for importations in full. Parts of Fort Hall and Central Nyanza come within this category, but probably the most notorious area is the Machakos portion of the Ukamba Reserve, which after a bad season in 1949 has had to import over 25,000 bags of maize (of 200 lb.) in December 1949, and rather more in January 1950. It is possible that more than this amount will have to be imported by the Reserve every month till September 1950. Probably a bag per head of population will be needed over the whole period, or say 250,000 bags. The cereals required in Ukamba and other famine-stricken areas can be supplied only from the European areas and from the less heavily populated native areas including North and South Nyanza. The former of these two Reserves exported about 550,000 bags of maize in 1949, or about a bag per head of the population. The maize was chiefly derived from the Kitosh Reserve where until recently some virgin fertility still remained

for exploitation, since the activities of this tribe had been largely pastoral until 10 or 12 years ago.

The African population in Kenya Colony according to official statistics has risen from under 3 million in 1930 to 5,150,000 at the 1948 Census. In this article I am not dealing with the effect of rising populations upon the native lands, but this phenomenon cannot be disregarded in writing of the European areas since it has the result that the European farmers are encouraged by Government to grow cereals—i.e. crops susceptible to soil erosion. Indeed, the present relatively high world prices for cereals and local prices, which if not on export parity have yet risen, have induced Kenya farmers to break more land for both wheat and maize; in any event a tendency which the opposite one of planting old arable land to ley grasses has not counterbalanced. Closer European settlement, with the breaking up of large holdings to form smaller units, may in the long run not be unfavourable in its consequence; that is if the units are not too small so that a regular grass-arable rotation is not only economic but practicable. There is, however, some likelihood of a higher intensity of use of the land bringing steep and erodible or sub-marginal land into cultivation. Likewise the need of many new settlers to find cash for capital development may induce certain of them to grow too many grain crops on the same land and to plant cereals on land which should have been restored to pasturage. A substantial increase in the wheat acreage is to be seen in some districts, e.g. the Ol Kalou–Ol Joro Orok districts, and on the Kinangop Plateau at an altitude of about 8,000 ft. below the Aberdares range.

From 1941 to 1949 inclusive 6,660 miles of broad base terraces have been built in the European areas of Kenya Colony covering 62,100 acres. This is exclusive of the area protected by narrow base and bench terracing, and does not take into account the large amount of work done in constructing farm roads, diversion ditches, drainage-channels, and other works. Possibly there are another 10,000 acres (at the outside) protected by farmers' own anti-erosion banks, excluding such partial measures as field or contour strip farming.

There were *c.* 520,000 acres of arable land under crop in 1949 (including *c.* 400,000 acres under cereals) needing protection. This acreage excludes the plantation crops of coffee (60,300 acres), tea (17,800 acres), and sisal (231,000 acres), which also require work to be done to prevent soil loss. Against this is the estimate (*v.s.*) that in the next few years 20,000 acres of arable land could be terraced annually by the S.C.S., including areas terraced by farmers independently of the Service. On the debit side there is likely to be a certain area of terracing lost each year due to bad maintenance. It would appear that even by the above possibly optimistic estimate of the rate of future progress, it would only be possible to get round the arable lands of the European areas in the next 25 years—and erosion works fast.

On the planning side, field officers of the Department of Agriculture stationed in the European districts estimated recently that, if necessary contour surveys could be supplied to them, they might be able to plan about 40 farms a year covering about 42,000 acres. This would, of course,

include grassland as well as arable, but estimating the farms on good and reasonably good land as covering 2 m. acres, including permanent grazing, this means that nearly 50 years would be required to plan the farms at the present rate of planning with the present staff available. On the other hand, there are doubtless many farms which are already put to something near optimum use and would not require much attention from officers of the Department of Agriculture; nevertheless it must be observed that farms which have been farmed for years by supposedly model farmers have been found on investigation to need drastic replanning both on the soil conservation and the agronomic side to give the best long-term economic use. Soil deterioration is not generally a spectacular process. Dirty palls of dust blowing thousands of miles from 'dust bowls' are not usual phenomena. Such events as wars and inflated prices, the beginnings of industrialization and other sociological events are apt to obscure what is happening to the land. The food situation or the industrial needs of other parts of the world, and consequent higher prices for food crops and raw products, may render it difficult for men not actually in contact with the farmers and the land to perceive that much land is deteriorating and even becoming sub-marginal. The deterioration of some of the older land may not be seen plainly in crop returns because a considerable area of virgin land has been broken for cropping as well as land which has been under grass for many years—since the time it was allowed to revert to grass during the disastrous slump of the early 'thirties. The use of superphosphates for some years may produce crops on land where the absence of traditional methods of permanent husbandry and the lack of a system leading to the constant replenishment of the organic matter of the soil is leading to its continued impoverishment. This, then, is one side of the picture: economic and political pressures leading to exploitative cereal farming; the insufficiency of staff either to replan land-use on farms along desirable lines—and we are dealing with rates of soil deterioration characteristic of the tropics—or to build rapidly enough the necessary anti-erosion works, even though substantial progress is being made.

On the other side of the picture is the growing interest in soil conservation methods and scientific methods generally; the increasing interest in mixed farming with dairy or beef cattle and in the use of planted grass leys; the probable availability of cheap phosphatic fertilizers in the next few years and of nitrogenous fertilizers from the large Owen Falls power scheme. The resultant of these forces will not be seen plainly for many years. Positive action by Government could sway the issue either way. The ever-rising African population and the demand for food both in this and other African territories may lead to an undesirable short-term policy of food production, an event which would also be enforced by a third World War.

Conclusion.—A rapid survey has been made of some of the main points in the erosion-control programme in the European areas of Kenya Colony. Although optimists sometimes talk of being able to dispense with mechanical aids to soil conservation if a good farming rotation is adopted, this is likely to be mere wishful thinking. The rapid decomposition of

humus and the torrential rains necessitate much more complicated measures to safeguard the soil than are needed, for example, in the chilly climate of England, with its gentle and persistent drizzling rains; and even in England erosion was not unknown, we are told, under the Celtic (pre-Roman) system of agriculture. By far the largest proportion of the terracing done in the European areas of Kenya has been done by the S.C.S., which up to the end of 1949 has protected 62,100 acres during the past 8 years, with 6,660 miles of terrace banks, in addition to many miles of diversion ditches, roads, drainage channels, &c.; but there are probably 500,000 to 600,000 acres of arable land which should be terraced. In most districts, including land at the higher altitudes near the Mau range, a large amount of erosion is continuing.

There is a growing appreciation of the need for comprehensive farm planning but, with the staff available, progress is likely to be slow. It may be asked why farmers cannot look after these things themselves. The fact is that complete conservation planning, particularly in a comparatively new country, demands a large fund of technical knowledge and experience which the average farmer cannot be expected to have, and does not have. Landscape gardening is a profession, and one which has to meet primarily only the aesthetic needs of the situation. Conservation farm planning has to consider not only topography, climate, and soils, but has to be fitted to the needs of the client's bank account, now and in the future. A bad plan can be disastrous to the land and to the farmer. It is certainly desirable to call in expert advice in such an important matter. Failure to make a conscious farm plan usually means the unconscious acceptance of a bad plan. Soil conservation farming in Kenya and good husbandry alike require a larger proportion of the land to be under grass. This raises immediately the economic difficulty that mixed farming or grassland farming is not always so profitable on a short-term view as exploitative monoculture of cereals. Further, higher capitalization is needed in buildings, fencing, dips, and live-stock for the former method of farming, and this extra capital many farmers and new settlers are unable to find. These, however, are difficulties that are appreciated by the Government of Kenya, and efforts are being made to meet it as a contribution to the long-term weal of the country. Considerable powers exist under the Land and Water Preservation Ordinance for Government to control the activities of the individual farmer in the interests of the community; but such control cannot be exercised equitably if, on the other hand, the community gives no aid to the farmer to enable him to farm better and to act as a worthy trustee of the resources of the soil of the country.

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FIG. 1. Drainage-line gully in wheat land; land now closed by order

FIG. 2. A wheat field, unprotected by an interception ditch, subjected to severe wash by run-off from a catchment area above

FIG. 3. Gully in large hill-top wheat field, one of many in land now closed to cultivation by order

FIG. 4. Contoured grass strips: pasture improvement

FIG. 5. Severe gully erosion caused by continuous monoculture of maize

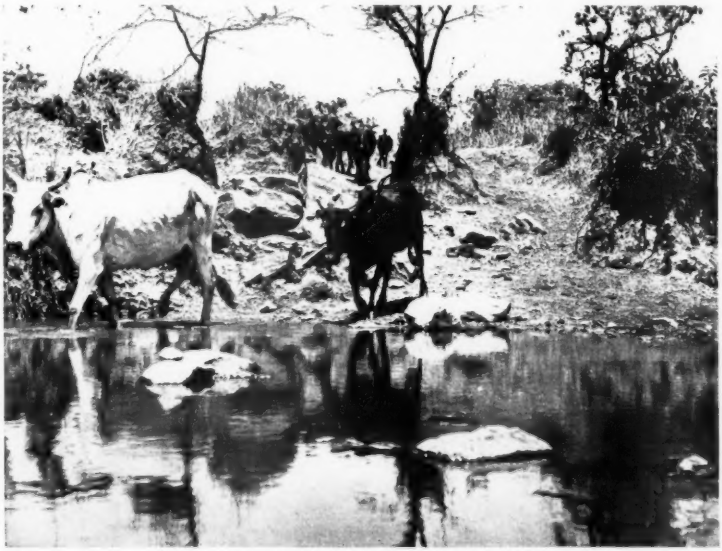

FIG. 6. Heavy erosion of river banks due to cattle tracks

FIG. 7. Gully erosion starting in a pyrethrum field in the Ol Kalou district. Note that the lines of pyrethrum were not planted on the contours (which were approximately at right angles to the direction of the wash)

FIG. 8. Severe gully erosion caused by continuous monoculture. Note stunted maize crop

GRAZING HABITS OF DAIRY COWS IN NEW ZEALAND

JOHN HANCOCK[1]

Introduction.—In recent years there has been an increased awareness of the complexity of the interacting factors that govern grassland production. Davies [1] has rightly pointed out that the grassland agronomist always works with ecological communities—the sward complex and the animal complex—which in their two-way reaction make the accurate evaluation of pasture yield a very difficult task.

The sward complex and the effects of the grazing animal on the sward have been investigated fairly thoroughly in the past, whereas the reaction of the sward (and other environmental conditions) on the grazing animal have not received nearly the same attention. Although feed-intake probably provides the best single index of a grazing animal's reaction to its environment, it seems certain that studies of the grazing behaviour of an animal can help to explain, in rational terms, its health and productive performance. It is also evident that if feed-intake studies are coupled with grazing-behaviour studies, a much more complete picture can be drawn of an animal's reaction to its environment than from either type of study alone.

The importance of observations of grazing behaviour has been stressed by Stapledon [2, 3, 4] and also by Hammond [5] and McMeekan [6]. The literature on the subject is rather limited and has been ably summarized by Johnstone-Wallace and Kennedy [7] and more recently by Tribe [8].

Most of the previous work on the grazing behaviour of our domestic animals suffers from at least some of the following limitations:

(*a*) The animals have been observed only in daylight. Any generalizations derived from such trials must be unsatisfactory in view of the evidence from all observations covering full 24-hour periods that an important part of an animal's total activities takes place during darkness. Further, it has been shown that certain climatological and seasonal conditions may alter profoundly the diurnal behaviour pattern of both cattle [9] and sheep [8]. The importance of these reactions of the animal to its environment could not be measured in trials where the observations were made only during daytime.

(*b*) Days of 'unsuitable' weather have been avoided for the convenience of the observer. Rainy days and moonless nights are two conditions that especially have been mentioned. Such non-random selection of trial days may have led to erroneous conclusions in cases when the avowed purpose of the trials has been the establishment of 'normal' behaviour pattern of grazing animals.

(*c*) Too few animals have been used. It is well known that even within a breed the individuals differ widely in their productive and growth performances. It is logical to assume that they show similar

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variations in their grazing habits. Conclusions based on the observation of only one or perhaps a few animals may therefore not be of general validity.

(*d*) Repeated trials on the same animals have not been carried out. This often makes it difficult to evaluate the significance of the results presented.

The present communication consists mainly of a general statement of dairy-cow behaviour in New Zealand based on 4 years' work in which nearly 2,000 cow-days have been recorded.

Dairying in New Zealand

The importance of grazing-behaviour studies in New Zealand can be best appreciated when considered in relation to the general conditions of dairying in this country.

Owing to a mild winter and a fairly evenly distributed annual rainfall of 40–60 in., dairy cattle are pastured all the year round. Despite the equable climate, the growth of grass is by no means uniform throughout the year; 60 per cent. of the total growth occurs in the 4 months, September to December. Dry weather in the summer months (January to March) generally retards the rate of growth appreciably, whilst early autumn rains provide a second flush of grass in the period March to May. In the winter months, June to August, low temperature is the limiting factor to grass growth, which almost ceases for approximately a month in the North Island.

To utilize the flush of spring grass, cows are calved down in the period mid-July to mid-September. In this way the peak of lactation synchronizes approximately with the peak of pasture growth. Some of the surplus spring grass is made into hay and silage and fed to the cows during the summer and winter. In the autumn some pastures are left ungrazed and the grass thus saved is fed to the cows as they calve down in the late winter.

Parallel with the seasonal changes in quantity, equally great changes occur in the quality of the available pasture. Ruakura data [10] indicate that grass grown in the spring is of low fibre-content and of high nutritive value, with a dry-matter digestibility coefficient of up to 80 per cent. Throughout the late spring a gradual deterioration occurs, a trend that continues into the late summer, when the digestibility coefficient may fall to the 60–65 per cent. level. Grass grown after the autumn rains is generally of the same high quality as in early spring. This also applies to the winter growth, when the grass, in addition, has an exceptionally high protein-content. Autumn-saved pasture, although of higher fibre-content, is only little inferior to spring grass.

The changes in quantity and quality of grass affected by climatological factors can either be minimized or accentuated, depending on the degree of skill and enterprise shown by the farmer, on the soil type on the farm, and on various economic factors that need not be discussed here.

The following farm practices appear to minimize the seasonal changes in the quantity and quality of pasture:

(*a*) Relatively low stocking-rate.
(*b*) Careful rationing of the available grass through close subdivision and rotational grazing.
(*c*) Surface harrowing in order to spread the dung.
(*d*) The use of the mowing machine or dry stock to eliminate stale grass and induce fresh growth after the milking herd has grazed over the pasture.
(*e*) The maximum conservation of hay, silage, and autumn-saved pasture.

By these methods dairy cattle can be provided with an even and high level of nutrition in spite of seasonal changes in pasture growth.

The seasonal unevenness in feed-supply is, in contrast, accentuated by the following conditions:

(*a*) Relatively high stocking-rate.
(*b*) Set-stocked grazing, which almost automatically makes it impossible to employ the refined techniques enumerated above.

Under these conditions dairy cows are submitted to periods of relative abundance, alternated by periods of semi-starvation.

For economic reasons it is only in exceptional instances that purchased concentrates or home-grown crops are used to supplement pasture and pasture products.

To sum up, dairy-cow nutrition in New Zealand is characterized by a series of ups and downs, the amplitudes of which depend partly on soil type and the severity of the seasons, and partly, perhaps more importantly, on the foresight of the farmer to provide in times of abundance for times of scarcity and his skill to manage the pastures to this end.

The almost total reliance on pasture and the great variability of the sward due to seasonal and human factors seem to justify all the effort which can be spared on investigations into the animals' reactions to the sward and other environmental conditions.

Technique and Material

As the technique adopted at Ruakura has been described in detail in a previous paper [11], the following short résumé is sufficient.

On predetermined dates the cows have been observed continuously for 24 hours. No trial has been postponed owing to adverse weather conditions. It has thus been possible to gauge the influence of various weather conditions on the grazing behaviour. The number of cows involved has varied from 12 to 30. The behaviour of each individual has been observed separately, making routine statistical analysis of the results possible. The recording technique has varied to some extent but is now standardized to a system where the various activities are recorded once every minute during daylight, and once or twice in every 5 minutes during hours of darkness, depending on the number of cows observed and the size of the enclosure. From preliminary trials in which a relatively restricted number of animals were observed on a ½-minute

basis throughout the 24 hours, it was found that the method used gives very accurate results.

Monozygotic cattle twins have been used in all trials. This has been a great advantage as it has been shown [11] that such animals are many thousands per cent. more efficient for this type of work than animals chosen at random from a herd of cows of the same age which have been reared together. In addition, the use of monozygotic twins has made it possible to measure the influence of environment-inheritance interactions on grazing behaviour.

The following activities have been recorded. Explanations are appended when thought necessary.

1. *Grazing time*—includes short periods of walking while selecting suitable grass for eating. Checks indicate that a minute in which less than 15 bites are taken are not counted in the grazing time. Actually there are exceedingly few minutes occupied in such a way that it is difficult to decide which activity to record.
2. *Loafing time*—comprises the time spent standing or walking while not grazing. This time thus includes the portion of the standing rumination time.
3. *Lying time*—includes the portion of rumination time spent in lying position and periods of total rest.
4. *Rumination time*—includes the total time, i.e. both lying or standing, spent in regurgitation, mastication, and swallowing of ruminal ingesta, and the short time-intervals occurring between boluses.
5. *Resting time* is derived by computation, and comprises that portion of lying time which is not occupied by rumination.
6. *Idling time* is also derived by computation and comprises the portion of loafing time which is not occupied by rumination.
7. *Distances walked.*
8. *Number of bites of grass.*
9. *Number of bites while ruminating.*
10. *Number of boluses.*
11. *Number of bites per bolus.*
12. *Number of defecations.*
13. *Number of micturitions.*
14. *Number of drinks.*

The following trials have been carried out to date:

1. *Uniformity trials on monozygotic twins and the collection of base-line data.* The following activities were constantly observed: grazing, loafing, and lying times; distances walked; number of defecations, micturitions, and drinks. Limited data were also obtained on the number of bites of grass, the number of jaw movements in rumination, and the number of boluses. Six sets of lactating 2-year old twins were observed on eight widely-separated, pre-selected days throughout the whole lactation in these observations.

2. *Influence of quantity of grass and of the feeding of concentrates on grazing behaviour.* Grazing, loafing, lying, and rumination times were recorded for 15 sets of monozygotic twins split into three groups, A, B, and C. The Group A cows received, in addition to a high-level grass feeding, 1 lb. of a concentrate mixture for every 5 lb. of milk produced. The cows in Group B were given grass on the same area basis as the previous group, but received no concentrates, whilst the C group also

was fed on pasture alone, but received on an area basis only 60 per cent. of the grass of the A or B groups. The animals were observed on 14 days spaced at fortnightly intervals over the main part of the dairying season.

3. *Inter-relationship between the grazing behaviour, dry-matter intake, and production of individual cows within a herd.* Ten sets of 2-year old monozygotic twins grazing together were observed during 4 fortnights spaced over the main dairying season. During the second fortnight, watch was kept continuously for 14 days; during each of the 3 other fortnights observations were made on 6 days. Grazing, loafing, lying and rumination times were recorded and, in addition, limited data were obtained on the speed of grazing and rumination. Individual dry-matter intakes were measured on a fortnightly basis by Dr. L. R. Wallace and his co-workers by a modified chromium-oxide 'marker' method. In addition, group-intake was determined by the 'crate' method [12]. On the first 7 days of the fortnight when the animals were observed continuously the grass was, although abundant, of relatively poor quality. On the 7 last days, in contrast, the sward offered to the cows was of high quality. It was, therefore, possible to draw preliminary conclusions on the effect of the quality of grass on the grazing habits and milk production of dairy cows.

4. *Influence of the quantity of grass offered on the inter-relationship of grazing behaviour, dry-matter intake, and production of individual cows.* The observations were made within the framework of the experiment described in (2) above, but in a different year and partly on different animals. The dry-matter intakes were measured as in (3). The 15 sets of twins were continuously observed on 5 days out of each of 3 fortnights. In addition to grazing, loafing, lying, and rumination times, limited data were obtained on the distances the cows covered within the 3 feeding-systems.

5. *Influence of rotational grazing and set-stocking managements on grazing behaviour.* The experiment within which these observations are being made has been described by McMeekan [6]. Twelve sets of twins are used and the trials will extend over a whole dairying season. The same activities as in (4) are recorded.

In these investigations daily milk and butter-fat production and weekly body-weights were recorded for all animals included in the trials (1)–(4). In trial (5), milk and butter-fat productions are recorded on a daily and weekly basis respectively, whilst body-weights are obtained fortnightly.

Only the chief aims of each trial have been outlined above. Throughout it was also possible to observe how such factors as individual idiosyncrasies, weather, time of the year, and herd habits modify grazing behaviour.

In the following discussion general trends only in grazing behaviour are presented. Detailed reports on the influence of the various factors under study in the experiments noted above will be reported separately. The experiments concerned are mentioned to provide a background to the observations that follow.

Results

The variations in grazing behaviour are discussed in terms of the following modifying factors: (1) Metabolic, diurnal, and seasonal rhythms; (2) weather; (3) quantity and quality of pasture; (4) individual idiosyncrasies; (5) environment-inheritance interactions; (6) 'herd' laws.

1. *Metabolic, diurnal, and seasonal rhythms.* As a general rule dairy cows in New Zealand divide their day into two periods of distinct activities: (*a*) the daylight period, when grazing is the main activity, and (*b*) the hours of darkness, when the main activity is rumination. Grazing activity follows a distinct pattern in that fairly long periods of continuous grazing are followed by shorter periods of idling, rumination, and even of total rest. Three or four periods of grazing thus occur between the morning and afternoon milkings; one or two immediately following the afternoon milking. In addition, the cows generally graze for a short period in the middle of the night. A grazing period may occur if morning milking is delayed beyond daybreak. The two periods following the enforced period of loafing during milking are generally the longest. Some cows, showing a typical grazing pattern, have been observed to delay rumination until the afternoon milking, indicating that the cyclic pattern of grazing is not caused by the need to ruminate at intervals. Generally the cows stop grazing soon after darkness falls, which causes the grazing period following the afternoon milking (*v.i.*) to become shorter and shorter from New Year onwards. However, in mid-April the hours of daylight become so short that the cows have not time to satisfy their appetites and therefore extend their afternoon grazing beyond nightfall.

The hours of darkness are mainly occupied by alternating periods of rumination and total rest. The height of ruminating activity (measured as the proportion of the time spent in ruminating) is generally reached soon after nightfall, when a gradual continuous decline takes place until the cows are brought in for milking. The decline in the ruminating activity is associated with shortening periods of rumination. The enforced period of loafing at morning milking is largely occupied by ruminating, but if milking is delayed and the cows left on the pasture, they will graze instead. Also if cows are disturbed during periods of rumination they may stop ruminating and after a while of idling revert to grazing. Thus it appears that the physiological urge to ruminate is not always compelling. Another interesting observation is that the change from ruminating to grazing is often abrupt whilst that from grazing to ruminating is not. Thus cows often begin grazing while masticating the last bolus, but a grazing cow will invariably allow some time to elapse before starting to ruminate.

The cows spend the greatest part of the ruminating time in lying position. They rarely ruminate while walking, although some cows do so especially when taken to and from the milking shed.

Whether cows ever sleep is a debatable point. Even at times of total rest they keep their eyes open except for some very short periods—a few minutes at most—when they generally rest their heads on the flank.

Dairy cows are much more sluggish in their behaviour during darkness than in the hours of daylight—they roam less while grazing and are generally not so easily disturbed. In the night, for instance, a car can be driven through a closely packed herd of cows without any noticeable effect, whereas a similar happening would cause much disturbance during the day. The occasional use of a flash-light during dark nights did not result in behaviour different in any manner from that occurring during moonlight nights when a flash-light was not necessary.

The rate of grazing (bites/min.) is on an average similar during day and night [11]. However, great variations occur throughout the 24 hours, in that the rate is generally highest in the beginning of a grazing cycle followed by a continuous steep drop towards the end. This indicates the necessity for caution in quoting rates of grazing if the counts have not been made over very lengthy periods.

The rate of rumination does not show variations of this type.

2. *Weather.* The observations of Seath and Miller [9] that hot weather alters the day-night grazing ratio seem unlikely to apply to New Zealand conditions as the weather during the dairying season is fairly equable. However, some weather effects, although of no great importance, are sufficiently distinct to be observable and are therefore described.

Cold, windy weather accompanied by frequent heavy showers tends to shorten the time the cows graze, as each shower forces the animals to drift with the wind until stopped by a fence or hedge, where they remain motionless with hunched backs until the shower passes. This applies also to cows grazing in an enclosure sheltered against the prevailing wind by hedges or trees except when the shelter is extremely dense.

In warm weather (75° F. or over) the loafing time during the day increases; the cows seem uncomfortable and seldom lie down for any length of time. Such weather has also the effect of dividing the grazing period that follows the afternoon milking into two parts separated by a period of lying. This may be due to the need of rest as in many cases the cows have been walking or standing for over 13 hours.

In this connexion it is well to realize that the effects of warm weather *per se* can easily be confused with the effects of the changes in pasture quality that are a normal consequence of the higher temperatures during the relatively dry summer months.

The number of times an animal defecates, urinates, and drinks in a day is partly determined by the weather. All three functions, but particularly the number of drinks, tend to increase when the daily temperature rises. The distances the cows walk also increase during warm weather. However, this may be due to increased irritation by flies rather than to high temperatures *per se*.

3. *Quantity and quality of pasture*—as factors influencing grazing behaviour are obviously so interdependent that they must be considered together. The influence of the total amount of pasture available to each cow on grazing behaviour will vary according to the length and density of the grass. It is, therefore, important to consider the quantity aspect in relation to the amount of grass available per acre as well as per cow.

Depending on the time of the season and grassland-management methods the following extreme situations may occur:

(*a*) Quantity high per cow and high per acre.
(*b*) " " " " " low " "
(*c*) " low " " " high " "
(*d*) " " " " " low " "

The grass offered the animals varies in quality, due to seasonal factors from young, highly digestible grass that generally contains little fibre, to mature, poorly digestible fibrous material. Poor pasture management often results in a sward of mixed quality during the season when grass of highest quality can be produced by previously related improved management-techniques. As each combination of quantity and quality modifies grazing behaviour in a particular way it is evident that the type of pasture given to the animals is a factor of great importance amongst those that determine the grazing animals' reaction to their environment.

In the following account, the available data, although fairly extensive, do not cover each possible combination, so that only a general outline is possible.

The activities directly affected by the pasture are mainly grazing and rumination. Other activities such as loafing, idling, lying, and resting are influenced only indirectly in that they can occupy only the time remaining after the grazing and ruminating urges have been satisfied. The grazing and ruminating times are interdependent and under certain conditions mutually restrictive. The nature of the pasture may either lengthen or shorten the grazing time or ruminating time, whilst the necessity to ruminate does occasionally limit the time available for grazing. For these reasons it is necessary to consider grazing and rumination simultaneously. This is partly achieved by noting how a specific type of pasture influences both grazing and ruminating times and partly by computing the ratio $\frac{\text{ruminating time}}{\text{grazing time}}$ (= the *rt*/*gt* value).

Abundant pasture, per cow as well as per acre, results in a short grazing time coupled with a short ruminating time if the quality is high but long ruminating time if the quality is poor; the *rt*/*gt* value is low in the first but high in the second case. If, however, the quality is mixed, the resulting grazing time becomes long, the ruminating time fairly long, and the *rt*/*gt* value relatively high. Poor and mixed quality pastures thus increase the work the animals have to perform; the former because the ingested grass necessitates longer ruminating time and the latter because the cows lose in efficiency of grazing as they try to select material of better quality. That they cannot be entirely successful in their selection is indicated by the relatively long ruminating time observed in connexion with mixed-quality pasture.

Quantitatively poor pastures, either per cow, per acre, or both, result in long grazing and short ruminating times, whilst the *rt*/*gt* values generally are very low, the lowest being reached when the quality of the grass is high. Given a fresh pasture each day, lactating dairy cows graze if necessary up to 10 hrs. as an average for a herd, though individual

animals may reach 12 hrs. a day. These values are considerably higher than have been noted in the available literature.

Under quantitatively poor pasture conditions the total working time is higher than under ideal conditions.

In conclusion it seems clear that cows must and do work longer hours under adverse grazing conditions, in that the time periods spent in grazing, ruminating, or both, are longer than when the pasture quantity and quality are optimal. Grazing habits are very sensitive to changes in pasture quality. When cows are changed to a new type of pasture the grazing and ruminating times will revert the very same day to those typical of the new pasture.

When cows are grazing good pasture in the same enclosure during the day and night, the day/night grazing ratio averages 60 : 40. If the pasture is quantitatively poor the ratio becomes 75 : 25, possibly because the cows are too tired to graze during the night, or because they are aware that no more edible sward is left.

4. *Individuality*. The use of monozygotic cattle twins in all grazing trials at Ruakura makes it possible to measure, with great accuracy, the degree to which grazing behaviour depends on individuality. In order to clarify the concept of individuality as far as grazing behaviour is concerned the analysis of one of these trials is discussed in some detail.

In trial (2) listed above, ten sets of monozygotic twins, all of the same age and at the same stage of lactation, were observed on 14 consecutive days. In the analyses of the resulting data there appear three sources of variation due to individuality: (*a*) Differences between sets of twins; (*b*) differences within sets of twins; and (*c*) error.

(*a*) The differences between sets of twins reflect the inherited variability in grazing behaviour. It was found that this was by far the largest source of variation due to individuality. Further analysis indicated that an important part of the inherited differences in grazing habits could be accounted for by the differences in nutritional requirements occurring between the ten sets of twins [13]. Or, in other words, greater maintenance, growth, and lactation requirements presumably resulted in greater feed-intake, which was achieved by longer grazing times and consequently longer ruminating times. However, the relationships between feed-requirements and grazing time or ruminating time was far from perfect. Some sets of twins seemed to graze, to ruminate, or to do both for excessively long times relative to other sets with similar feed-requirements. Nor were the resulting dry-matter intakes in many cases proportionate to grazing or ruminating times. The most likely explanation of this situation is that some animals, due to their inherited make-up, are less efficient grazers than others in that their intake per grazing-time unit is relatively low. This can be achieved by fewer bites per minute, by smaller intake per bite, or by a combination of each. Low grazing efficiency may be due to a variety of anatomical features such as narrowness and shortness of the lower jaw, but it seems that the main reason is that some twins select the grass they eat to a greater degree than others. The evidence for this [13] rests on subjective observation and on the following facts: (*a*) differences in speed of grazing (bites/min.)

have been demonstrated to occur between sets of twins, and (*b*) the *rt*/*gt* value is a characteristic specific to each set of twins [13]. The latter piece of evidence may, however, be of limited validity as it is possible that other factors such as differences in ruminal digestion can cause variations in the *rt*/*gt* values even if the twin sets have consumed grass of similar quantity and quality.

The likelihood that selective grazing is a characteristic affecting grazing efficiency and thus feed-intake opens up a field of interesting speculations. Briefly, it seems that a selective grazer compared with an unselective grazer of the same inherent productive ability will be at an advantage as far as milk production is concerned, when grazing a mixed quality pasture, whilst the same animal will perform relatively poorly when the pasture is in short supply. In the first case the discriminating grazer will select only the high-quality grass and thus obtain, if it grazes sufficiently long, a high intake of digestible nutrients in spite of the prevailing pasture type. The unselective grazer will, on the other hand, consume both good and poor grass to an equal extent and will thus obtain a full food-intake in a shorter time. However, the fact that the ingested food contains less digestible nutrients will be reflected in a lower production. In the second case, selective grazing will result in a total feed-intake that is too low for full production however long the grazing time, whereas the animal which is not so particular about the type of grass it eats can obtain a full feed-intake in spite of the scarcity of grass. Finally it can be stated that in conditions of pasture shortage, grass rejected by the selective grazers is of as high, if not of higher nutritive value, than the grass actually consumed, and consists mainly of material growing on and around urine and dung patches.

The discrimination against soiled pasture is very strong in some sets of twins. Amongst the animals observed in the trial described above, two sets of twins grazing in a fresh enclosure found the grass after a few hours so little to their liking that they regularly spent a great portion of their remaining grazing time with their heads through the fences trying to obtain clean grass.

Inherited individuality in grazing behaviour is also apparent in other traits. The members of the same sets of twins show for instance, pronounced similarity in the frequency of drinks, defecations, and micturitions, and also in the speed of rumination (bites/min.), number of bites to each bolus, and the average length of the rumination periods [11]. There is a rough relationship between the total rumination time and the last-mentioned characteristic. The demonstration of individual differences of this kind demonstrates that there exist corresponding differences in the underlying metabolic and catabolic processes. However, further inquiries are needed to evaluate the significance of these findings.

Inherited individuality also influences the distances cows walk when on pasture [11]. There is a tendency for the cows which graze a relatively long time to cover correspondingly greater distances. The relationship between grazing time and the distances walked, however, is not perfect. A sluggish disposition, for instance, may cause the members of a twin set to walk less than would be expected from their grazing times.

Other individual idiosyncrasies of minor importance have also been observed. In a herd which was milked so late in the morning that the cows developed a habit of grazing before they were brought in for milking, it was noted that the members of a particular set of twins were regularly the last ones to begin grazing. As these twins had been separated at birth and had no contact with each other until they were 2 years old, they did not know each other; imitation, therefore, could not have been the reason for the similarity of their behaviour.

The positions a cow holds her head when ruminating seem to be an inherited characteristic since twins behave very similarly. Normally cows ruminate, when lying, with heads held fairly high and necks stretched, presumably to allow the ingesta an easy passage. One set of twins, however, was noted to ruminate invariably with the mouth almost at ground level, and the members of another set sometimes ruminated with the heads resting against the flanks.

(*b*) The 'within set' difference in grazing behaviour as a source of variation due to individuality can be detected in time-repeated trials as consistent differences occurring between the members of the same set. Such differences are almost invariably found only in twin sets in which the members differ in their nutritional requirements for maintenance growth or production. Grazing and rumination and dry-matter intakes of such sets are generally proportional to the total feed-requirements of each member. It is hardly possible to decide with certainty whether a decreased appetite causes a lowering in growth-rate or milk production, or whether a lower growth and lactation-urge cause a decreased need for nutrients and, therefore, an alteration of the grazing behaviour. The latter proposition seems to be easier to sustain, as lactational accidents and slight indisposition may well cause a drop in production and growth-rate, whereas if appetite determines the level of production and growth, one is still faced with the task of explaining the causes of variation in appetite.

(*c*) The third source of individual variation in grazing behaviour is represented by the error term, which is caused by inconsistent day-to-day differences within sets of twins. Such variations may be quite considerable. The only cause of differences of this kind known with certainty is oestrus, which effects a drop in both grazing and rumination times.

5. *Environment—inheritance interactions* have been measured using monozygotic twins as experimental material in time-repeated trials; these (days × sets interactions) are observable in so far as some sets of twins react to a new environment (day) in a specific manner or to a more pronounced degree than the other sets employed. Statistically significant interactions of this type have been found in respect of the following activities: Grazing, loafing, lying, and rumination times; the distances cows walk, and the number of micturitions and drinks [11]. The interactions observed in respect of the grazing and ruminating times can be explained on the basis that the most selective twin sets (to judge from their long grazing times and low *rt*/*gt* values) show grazing times and *rt*/*gt* values much nearer the average when grazing on excellent pastures

than when grazing sward of mixed quality. It has been previously noted that loafing and lying times, the distances walked, and the number of micturitions and drinks are affected by warm weather. The environment-inheritance interactions observed in respect of these characteristics seem to be due to some sets of twins reacting more strongly to warm weather than others. Similar interactions, incidentally, have been recorded in respect of the thermo-regulatory processes measured in terms of body-temperatures and respiration rates [13]. Interactions in respect of loafing and lying times may also occur as epiphenomena to variations in grazing times of the type described above.

6. '*Herd laws*.' The fact that dairy cows are grazed in herds and not singly in an enclosure affects their habits to some extent. A herd pattern, for instance, exists especially in the case of the grazing activity in that all cows tend, within limits, to begin grazing simultaneously. Partly, at least, this herd pattern is man-made and depends on such factors as the time at which the cows are taken in for milking and allowed out on the pasture, and on the type of sward they are grazing. However, the habit of unison grazing persists even when the natural behaviour pattern is not interrupted by milking, i.e. when the cows are dry. The factors that determine the exact timing of each cycle are not known. No well-defined leader, for instance, has been noted which would initiate a new cycle. However, that some kind of 'herd laws' must determine the behaviour of cows on occasions is shown by the following. A herd of twins was divided into two lots, one of ten sets and the other of seven sets, and were subsequently grazed in adjoining enclosures, separated from each other only by a single wire. The herds were taken simultaneously to and from the milking-shed. It was repeatedly observed that the habits of the two herds were different in that all the animals of one herd could be in the midst of a grazing cycle while the cows in the other herd were all loafing or lying.

The inclination to ruminate can be suppressed if most of the other cows continue to graze. It often happens that a few individuals after a short period of idleness in the middle of a grazing cycle begin to ruminate. When, however, the remainder of the herd moves away in search of feed, the ruminating cows tend to follow and, after a few minutes, stop ruminating and begin to graze.

The herd instinct is also noticeable in the manner in which all cows tend to be concentrated in a relatively small portion of the enclosure. This inclination is strongest in periods of loafing or lying (especially during the night), but also when grazing it is unusual for cows to be spread over more than a quarter of a big enclosure (10–20 acres). In a smaller enclosure the dispersion is relatively greater, but regular herd movements are observable even under these conditions. In a long, narrow enclosure the herd moves from one end to the other; in a squarish enclosure the movement tends to be circular. In warm weather dairy cattle stay closer together than otherwise, possibly in order to make the defence against the increased fly nuisance more effective. Extraordinary rapid changes in this behaviour have been observed on warm days when periods of direct sunshine alternated with periods of clouds shading the

sun. Immediately the sun appeared from behind a cloud the cows gathered together and continued to graze or loaf so closely bunched that one cow touched the other. They dispersed equally suddenly when the sun clouded over.

Unusual disturbances, such as straying dogs and passing cattle, frequently result in the simultaneous abandonment of the normal current activities and a wild rush, accompanied by bellowing, is made toward the source of disturbance. After this has passed all cows, whether they previously grazed or ruminated, tend to graze.

On very rare occasions a peculiar herd reaction has been observed. The cows suddenly stop motionless, lift their heads high in the air and remain thus for a few minutes, whilst many of the animals utter a low bellow, which is made without opening of the mouth. The reversion to normal activities is equally sudden. The reason for this behaviour has not been ascertained.

The strong affinity of monozygotic twins presents a special case of gregariousness. Thus members of a set of twins after having strayed some distance apart while grazing, seek each other's company at frequent intervals. Not all twin sets, however, behave in this manner. Some sets of twins actually do not stay together more than if they were randomly selected animals within the herd [11]. In the face of presumed danger, as for instance, in encountering a dog, the members of all sets of twins, no matter how slight their normal affinity, stay close together in mutual defence.

A ranking (bunting) order similar to the well-known pecking-order in flocks of fowls, occurs in herds of cows. This phenomenon was investigated in conjunction with the trial [3] described earlier when the grazing behaviour of ten sets of twins was observed for 14 consecutive days. Each occasion of fights between two cows was noted. The collated results are shown diagrammatically in Fig. 1.

A detailed examination of the diagram reveals the following: (1) The bunting-order although fairly clear-cut was not perfect. The sets 1–2, 5–6, and 7–8 (as indicated by double arrows) for instance, were involved in fights amongst each other, which were sometimes lost and sometimes won. These three sets thus occupy approximately the same position on the ranking list. Lower on the list, the sets 9–10 and 13–14 also occupy an equal position. The positions of the sets 3–4, 15–16, and 19–20 are in some respects aberrant; 3–4 beat 1–2 but lost to 5–6, although the two last sets were equal; 15–16 lost to 19–20 but beat both 9–10 and 13–14 which in their turn beat 19–20. All possible combination of fights between the various sets were not seen, although the observations were made over an extended period; 1–2 was the only set seen involved in fights with all other sets, whilst in the other extreme the set 5–6 fought only the members of five other sets. Both members of a set occupied strictly the same position on the bunting list, indicating that the hereditary disposition of an animal determines its rank order at least in a herd where all animals are of similar age. The twins in this sample never fought each other. In the same sample employed in the trial (1) however, the members of one set were involved quite frequently in violent fights,

which always ended in a draw; a situation which has not been observed in non-twins.

Discussion

The proper task of a grassland farmer is to build up and manage his pastures in a manner likely to ensure maximum net profits over a number of years. In the past, attempts have been made to use the knowledge gained from grazing-behaviour studies to measure the relative success

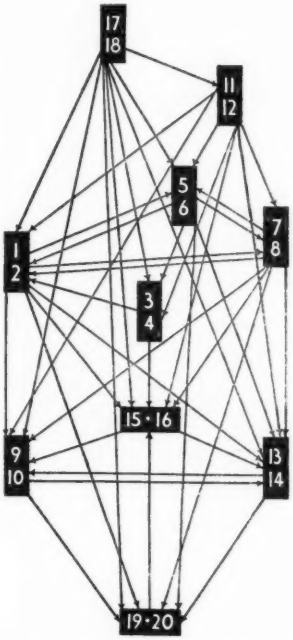

FIG. 1. 'Bunting order' in a sample of 10 sets of monozygotic twins.

of various management practices, the underlying assumption being that on the comfort and well-being of the cows (measured by their grazing behaviour) depends their ability to produce at maximum capacity, which in turn is the factor that determines net profits. In order to avoid fruitless discussions, it is necessary to test carefully this double assumption.

It seems that the highest degree of well-being and comfort is reached by cows grazing on pastures which are abundant, measured per acre and per cow, but which are of relatively poor quality with fairly high fibre-content and low digestibility. Under these conditions, which frequently occur in the early summer on lightly stocked farms, the cows put on weight and are remarkably free from all digestive disturbances, but even mediocre animals cannot produce to the limit of their inherited ability.

The grazing times are very short, the rumination times relatively long, and the *rt*/*gt* values very high.

Maximum-per-cow productions are likely to be obtained when the cows are provided with an abundant pasture of highest quality, i.e. of the low fibre-content and high digestibility typical of fast-growing spring grass. The health status of the animals grazing a sward of this kind is often lowered by digestive upsets (scours, bloat) and the cows generally lose weight, but even good cows are able to produce almost to their inherited genetical ceiling. The grazing times are relatively short, the rumination times short, and the *rt*/*gt* values low.

There are, however, indications [14] that maximum production per cow do not necessarily yield the greatest net returns. It seems that net returns are intimately connected with management methods which ensure that all grass at all times of the year is completely utilized. In practice this can be achieved most conveniently by employing a stocking-rate which is too high either to sustain maximum productions or perfect health and comfort. Under such conditions the grazing times are long, the rumination times short, and the *rt*/*gt* values very low.

The above discussion clearly indicates that it is necessary to define precisely the point of vantage from which judgements on pasture-management methods are passed in the light of ensuing grazing behaviour.

The data and analysis on which the present paper is based will be published in full in due course. Meanwhile it is hoped that this discussion has indicated to workers in this relatively new field some of the possibilities and pitfalls involved.

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PASTURE PRODUCTIVITY IN MID-WALES

Pt. II. BOTANICAL CHANGES IN THE EXPERIMENTAL PLOTS: PALATABILITY AND 'EFFICIENCY' OF THE SWARDS

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WITH PLATE 14

Botanical Changes in Experimental Plots as related to Productivity Data

THE fact that Technique 2 gave a higher relative yield from the manured permanent pasture in 1947 than in 1946 (Pt. I, p. 214) is consonant with the marked botanical improvement that occurred in this pasture from 1946 to 1947 (Table 1). The experience obtained with this technique therefore supports the view expressed by Linehan, Lowe, and Stewart [1] that the movable-cage method provides a good measure of pasture output.

The whole experimental area was initially an Agrostis sward (bent) with proportions of the better grasses and wild white clover. Of these species perennial rye-grass and crested dogstail each comprised approximately 9 per cent. of the total number of tillers, rough-stalked meadow grass 12 per cent., and wild white clover 11 per cent. The rye-grass, white clover, and the small amount of cocksfoot present were all of an indigenous type as the sward was an old permanent pasture. In the original herbage red fescue was present only to the extent of $2\frac{1}{4}$ per cent. of the total number of tillers, but as indicated below the subsequent treatment had an important effect in increasing the proportion of this and other constituents. Under the influence of the rotational grazing over the 3-year period under review, some changes also took place in the control plots. There was a small increase in the proportion of perennial rye-grass and more especially of fine-leaved red fescue, and a corresponding decrease in bent and sweet vernal. The crested dogstail remained little changed, but Yorkshire fog increased by 1947 owing to the high water-table in Plot 1B of the control series (Plate 14A). The herbage became finer and wild white clover increased.

It was in the manured permanent-pasture plots (plots 2, 2A, 5, 5A) that the botanical composition showed a marked improvement. In these plots the proportions of perennial rye-grass and wild white clover were more than doubled by 1947, whilst in some of them fine-leaved red fescue increased considerably, these increases being accompanied by corresponding decreases in bent and sweet vernal. The small amounts of crested dogstail and Yorkshire fog also showed a decrease, but the miscellaneous-herb group remained constant in its relatively low amount. The sward type is shown in Plate 14B.

Details of the species sown in the ploughed areas have been given (Pt. I, p. 215), and one of the chief botanical changes observed in these seeds-mixture plots during the 3 years was that Italian rye-grass contributed appreciably to the herbage during 1945 and 1946, but, as expected, little remained of it by 1947. In 1947 the sward formed a

[Empire Journ. of Exper. Agric., Vol. 18, No. 72, 1950.]

dense pasture composed almost entirely of perennial rye-grass, cocksfoot, and wild white clover (Plate 14C).

Although there had been an excellent 'take' of seeds, the white clover plants did not at first provide the quantity of herbage desirable in proportion to that from the grasses. Consequently in July of the second year white clover seeds were broadcast on the surface and scratched in, the same pedigree strains and amount per acre being used as in 1945. The resulting growth of clover in the latter part of 1946 and throughout 1947 was sufficient to provide a more balanced relationship of grass to clover.

Practically no grass or miscellaneous weeds appeared in the seeded areas and they remained almost 100 per cent. of sown species throughout the 3 years. As previously mentioned, the excellent 'take' ensured a good ground-cover and as pedigree strains of the rye-grass and cocksfoot comprised the major portion of the seeds-mixture sown, there was high tillering capacity. The detailed changes that occurred in the different swards from one season to the next during the experimental period are shown in Table 1 (page 226).

Palatability and Efficiency of Reseeded Grass and Permanent Pasture

As indicated above, the reseeded grass was confined almost entirely to two strains of grass species and wild white clover, but the permanent grass was heterogeneous, containing many grasses and miscellaneous herbs. In 1946 the reseeded grass was more thoroughly grazed than the permanent pasture, and this occurred again in 1947, as shown by the following figures giving the mean quantities of uneaten grass in grams per square yard left behind at the end of the grazing periods:

Control plots (unmanured permanent pasture)	
1, 1A	160
1B, 1C	169
Mean	165
Manured permanent-pasture plots	
2, 2A	180
5, 5A	187
Mean	184
Reseeded and manured plots	
3, 3A	78
4, 4A	62
Mean	70

The data derived from this experiment show that the sheep found the reseeded grass more palatable and grazed it more thoroughly than the permanent pasture, but their natural inclinations were most fully satisfied when they had access to a supply of both types of herbage.

A unique feature of this experiment is that in some of the plots the herbage consisted partly of permanent pasture and partly of reseeded grass. Such a method of experimentation has made possible observations on the behaviour of the grazing animal when presented with a choice of

TABLE 1. *Botanical Composition of the Swards of the Unmanured Permanent-pasture Plots (Controls), the Manured Permanent-pasture Plots (P.P.), and the New-seeds Plots. Data expressed as Percentage Tiller Composition*

Plots	*Perennial rye-grass*	*Cocks-foot*	*Crested dogs-tail*	*Rough-stalked meadow grass*	*Bent (Agrostis spp.)*	*Sweet vernal*	*Yorkshire fog*	*Red fescue*	*Wild white clover*	*Miscel-laneous herbs*	*Tillers per 6×6 in.*
All P.P. areas in 1945*	8·5	1·5	9·3	12·5	40·2	6·3	5·8	2·3	11·3	2·3	450
Controls in 1946. .	9·1	3·1	6·9	11·9	37·0	3·6	7·9	5·0	12·5	3·0	460
Controls in 1947. .	9·4	3·8	8·4	8·1	28·4	1·9	15·1	11·0	12·3	1·6	465
Manured P.P. in 1946.	11·9	3·8	7·5	11·7	32·4	2·7	5·4	6·8	15·0	2·8	467
Manured P.P. in 1947	17·3	4·3	7·7	9·6	14·1	0·9	3·0	17·9	23·2	2·0	482

New Seeds	*Italian rye-grass*	*Perennial rye-grass*	*Cocksfoot*	*Rough-stalked meadow grass*	*Other grasses*	*Wild white clover*	*Miscellaneous herbs*	*Tillers per 6×6 in.*
Seeding year 1945†	30·0	48·8	18·0	..	Trace	3·0	0·2	234
In 1946 . .	14·1	53·2	25·7	Trace	0·8	5·7	0·5	283
In 1947 . .	Trace	46·5	39·9	0·7	1·5	10·6	0·8	346

* Average of all the permanent-pasture areas at the beginning of the experiment.
† Average of all new-seeds areas 2½ months after sowing.

swards. The importance of such a choice has been recently stressed by Stapledon, who mentions that animals on free range moved in a comparatively regular manner from one type of sward to another [2].

In plots 5, 5A, which consisted of 75 per cent. permanent pasture and 25 per cent. of reseeded grass, there was greater concentration of the grazing on the reseeded area, with the result that the dry matter left ungrazed from the ley in these plots amounted only to a mean of 27 gm. This compares with a mean of 187 gm. on the permanent-pasture portions of the same plots, and a mean of 78 gm. in plots made up entirely of reseeded grass (3, 3A). This behaviour of the sheep in plots 5 and 5A resulted in a very close sward on the ley, a state of affairs which brought about a greater proportion of clover to grass than in the other reseeded plots.

In plots 4, 4A, which consisted of 75 per cent. reseeded grass and 25 per cent. of permanent grass, the sheep grazed the restricted area of permanent pasture harder than in the plots made up either entirely or mainly of permanent grass. Consequently only an average of 102 gm. per sq. yd. of permanent grass was left ungrazed on these plots, compared with an average of 184 gm. on plots consisting wholly or mainly of permanent grass. On the other hand, even on these plots of low-proportion permanent pasture, the areas of reseeded grass on the same plots were more thoroughly grazed than the permanent grass, there being only 62 gm. per sq. yd. of the reseeded grass left behind.

The data obtained over the two harvest years 1946, 1947 throw light on the relative efficiency of the two types of swards for live-weight increase. Below are given the live-weight increases expressed as lb. per acre for 2 seasons.

Control plots	*1946*	*1947*	*Mean of 2 seasons*
1, 1A . .	302	218	260
1B, 1C . .	242	280	261
Mainly permanent pasture, manured			
2, 2A . .	282	258	270
5, 5A . .	340	304	322
Mainly reseeded, manured			
3, 3A . .	361	274	318
4, 4A . . .	340	312	326

Thus in both seasons the manured plots made up entirely of permanent pasture (2, 2A) gave a better live-weight increase than the unmanured control plots; but the manured permanent-pasture plots containing 2·5 per cent. of reseeded grass (5, 5A) were markedly superior to the control plots. This adds to the significance of the fact that the reseeded grass was much more closely grazed in these plots than in any others and suggests that it contributed a factor which was deficient in the manured permanent grass. The live-weight obtained from all manured plots containing from 25 to 100 per cent. reseeded grass has been remarkably

similar (plots 5, 5A, 4, 4A, 3, 3A), showing a gain of 23 per cent. on the live-weight increase obtained from the control plots. It cannot be inferred from this experiment that this increase would have been forthcoming from reseeded grass in the complete absence of permanent grass. As previously mentioned, where the plots were made up entirely of reseeded grass the sheep tried persistently to reach the permanent-grass border outside the fence. The small amount of grass which they were successful in obtaining in this way, although negligible in comparison to the total bulk of food eaten, may yet have made an important contribution towards their progress.

The above increase of 23 per cent. in live-weight obtained as a result of reseeding occurred on a very dense sward of permanent grass containing appreciable amounts of the better species, the composition of which had been greatly improved by manuring and controlled grazing. In this connexion it is noteworthy that on a super-grade permanent pasture in Leicestershire, Davies and Williams [3] found that the live-weight increase was approximately equal to that from a young ley over a 3-year period. On a typical Leicestershire permanent pasture the yield was 18 per cent. below that from a young ley, whilst similar comparisons between leys and permanent pastures of progressively lower grade showed greater differences in favour of the young ley. In an early experiment carried out by Jones [4] an average difference of 45 per cent. in favour of a young ley was found where the temporary ley consisted mainly of Italian rye-grass and Montgomery red clover, and where the permanent pasture was one of poor quality.

One question of wide interest is whether a given quantity of ley grass of restricted botanical composition can contribute as much towards animal maintenance and production as the same quantity of permanent pasture containing a greater variety of plant species. It has been explained that whereas Technique 1 tended to give too low an estimate of the grass actually consumed by the sheep, Technique 2, with its lenient treatment of the grass, tended to give too high an estimate. The nearest approach to an estimate of the grass consumed by the sheep in this experiment can therefore be obtained from an average of the two techniques. An estimate of the grass consumed for the two harvest years has accordingly been arrived at by averaging the data of the two techniques expressed in terms of starch equivalent. An estimate of the sheep maintenance and production has been obtained from the sheep weights and expressed in the same terms. On page 269 we give the starch equivalent utilized for maintenance and production from every 100 lb. of starch equivalent consumed.

As previously emphasized the figures below have only a relative value; wide variations occurred in the efficiency of utilization of the grass on the control plots. The efficiency on the manured plots was more constant, particularly on the plots made up mainly of reseeded grass. These figures show that an estimated consumption of 100 lb. starch equivalent derived from reseeded grass provided at least as much energy for animal maintenance and production as an estimated consumption of 100 lb. starch equivalent derived from permanent pasture.

	Estimated starch equivalent	
	Grass consumed (based on average of cutting techniques)	*Used for maintenance and production (derived from) sheep data)*
Control Plots		
1, 1A . . .	100	88
1B, 1C . . .	100	121
Mainly permanent pasture manured		
2, 2A . . .	100	86
5, 5A . . .	100	95
Mainly reseeded, manured		
3, 3A . . .	100	107
4, 4A . . .	100	109

In view of the opinion widely expressed that physiological disorders are much more common on leys than on permanent pastures, it should be stated that the sheep and lambs on both the ley and permanent-pasture plots in this experiment were entirely free from such disorders.

Summary

1. The botanical composition improved markedly over the 3 years of the trial. The proportion of the better species in the manured permanent pasture plots more than doubled by 1947, and there was also a definite improvement in the unmanured control plots. In the reseeded plots the decrease of the Italian rye-grass was followed by an almost pure sward of the permanent sown species.

2. Measurement of the grass left behind at the end of the grazing periods proved that the reseeded sward was far more thoroughly grazed than the permanent pasture.

3. Estimated consumption (based on the cutting techniques) of 100 lb. starch equivalent derived from reseeded grass provided at least as much energy for animal maintenance and production as an estimated consumption of 100 lb. starch equivalent derived from permanent pasture.

4. Over the two harvest years the control plots gave an average gain in live-weight of 261 lb., the average gain from the manured permanent pasture being 270 lb.

5. The gains in weight from all manured plots containing an area of from 25 to 100 per cent. reseeded grass were similar, showing an average of 322 lb. per acre, and an increase of 23 per cent. on the gain in weight derived from the control plots.

6. The experimental data indicate that the manured permanent grass was not fully adequate for the production of live-weight increase, and that its deficiency was remedied by the presence of a 25 per cent. strip of reseeded grass.

7. No evidence arises from these experiments that the reseeded grass with its restricted flora disturbed the physiological equilibrium of the grazing animal.

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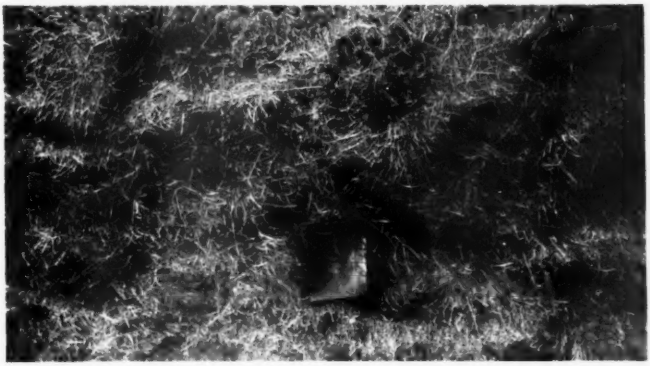
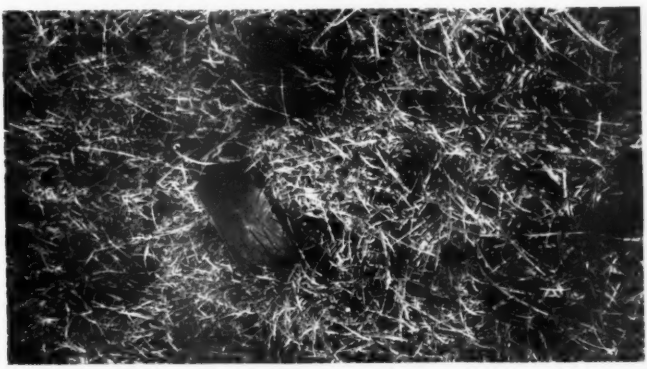
(*Received March 17, 1950*)

a. Unmanured permanent pasture (the control plots) in September 1947. The better grasses and wild white clover had increased since April 1945



b. Manured permanent pasture in 1947. A marked increase of perennial rye-grass and of wild white clover since 1945 with a decrease in the proportion of bent (*Agrostis*)



c. The ley in plot 3 by 1947, consisting of a mixture of strains of perennial rye-grass, cocksfoot, and wild white clover. Sown in April 1945

PHOTOPERIODISM IN RICE IN TRINIDAD WITH REFERENCE TO A SECOND CROP

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SWAMP rice in Trinidad is normally grown as a single main crop, which is sown in June and July, transplanted a month later, and harvested in November. This period corresponds with the wet season which begins at the end of May and continues with a slight break in October until the end of December.

When experimental work on rice was begun in 1947 it seemed that one obvious way of trying to secure increased production lay in attempting to grow two crops a year on such land as was served by irrigation-water. This is common practice in most of the rice-growing countries of the East where water supplies and other conditions are suitable.

On some of the rice-lands where irrigation-water is available, vegetables are grown after rice, but the heavy clay in other areas does not support good crops of vegetables, and little use is made of the land after the rice has been harvested. A small crop is sometimes taken from tillers springing from the cut stools, but this ratoon crop is hardly worth cutting. More generally the land is left to grow weeds and grass, which serve at best as a rather poor source of grazing for the farmer's livestock.

Now, the rices grown in Trinidad are nearly all 5-month rices and it seemed feasible to try a cropping plan along the following lines:

Early June:	Broadcast nurseries with the first rains.
Early July:	Transplant to the swamp.
Early October:	Broadcast nursery for the second crop.
Early November:	Harvest first crop and plough immediately for the second crop.
Mid-November:	Transplant second crop.
Mid-March:	Harvest second crop. This would be brought to maturity with irrigation-water in January and February after the rains have ceased.

Spasmodic attempts had been made in the past by farmers to grow a second crop, using the same variety as the main crop but always with very poor results. It was generally considered an uneconomic practice, but no satisfactory explanation had ever been offered.

Experimental Work in 1947

A $\frac{1}{4}$-acre field was selected on the rice experimental plots of the Department of Agriculture at St. Augustine for carrying out the cropping plan outlined above.

The latitude of the station is approximately 10° 40′ N. and the elevation is about 50 ft. above sea-level.

[Empire Journ. of Exper. Agric., Vol. 18, No. 72, 1950.]

The variety used was Joya, a local rice whose history is unknown, but it was probably introduced from India in the last century by indentured labourers who came from India to work on the sugar estates. This variety is normally a 5-month rice and yields well under Trinidad conditions.

The cropping programme was carried out as planned and the resulting yields in pounds of paddy per acre were: 1st crop 4,080; 2nd crop 1,380, i.e. the return from the second crop was only one-third of the main crop though growing under apparently good conditions. Therefore it seemed reasonable to conclude that Joya was a season-limited rice.

At the same time a series of monthly plantings had been started to give further information on the growth and yield of Joya planted out of its normal season. Every month a plot of approximately $\frac{1}{25}$ acre was transplanted with seedlings sown a month earlier, and a record was kept of the time at which the plot started to flower and of the yields secured. These plantings have been continued for 2 years and the results are summarized in Table 1.

TABLE 1. *Growth and Yield of Joya Rice planted out of Season*

Sowing date	*Days to flowering*	*Days to harvesting*	*Plot yields (lb.)*
3.6.47	109	162	172
4.7.47	95	145	130
5.8.47	88	139	105
5.9.47	89	146	81
6.10.47	86	148	68
5.11.47	86	157	80
3.12.47	85	136	65
3.1.48	97	..	..
13.2.48	191	269	30
5.3.48	165	238	70
5.4.48	..	..	..
5.5.48	133	180	112
5.6.48	110	159	148
5.7.48	..	..	..
17.8.48	91	139	80
6.9.48	90	142	63
5.10.48	86	145	63
5.11.48	92	147	61
13.12.48	92	140	50
5.1.49	..	..	..
5.2.49	188	..	..
5.3.49	..	..	..
5.4.49	..	..	..
5.5.49	140	187	130
6.6.49	111	155	142

Gaps are due to unforeseen circumstances, mainly failure of irrigation-water.

Although not replicated, the differences found in time to flowering and harvesting, and in final yields, are so marked as to confirm that Joya is a season-limited rice responding strongly to the photoperiod

of the season in which it is grown. The results are shown graphically in Fig. 1.

A striking field demonstration of the existence of photoperiodism in Trinidad rices also occurred in 1947 and has been described by Benson and Murray [1]. A waste gas-flare from an oilfield burning night and day completely inhibited flowering in the rice-field around. Where

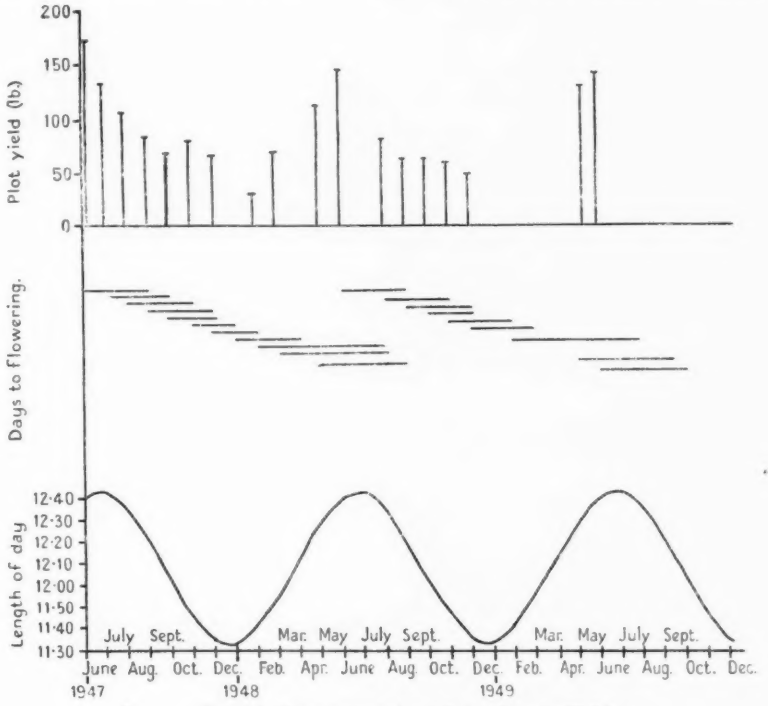

FIG. 1. Graphical representation of the data in Table 1.

bushes and small trees were growing on the bunds and casting a shadow from the flare at night, the rice flowered normally and the shadow patterns of flowering rice were plainly visible in the non-flowering rice around. On the flare being extinguished, compensation for the crop being involved, the rice at once flowered and bore a normal crop.

The existence of a marked photoperiodism in Joya having been demonstrated, it was clear that normal methods of planting for a second crop would never result in satisfactory yields, but it was necessary to determine whether better yields could be secured by modified cultural practices.

Experimental Work in 1948

The same field used in 1947 was cropped in 1948 and gave 3,800 lb. paddy per acre for the first crop. It had been observed that tillering

and height of plant were reduced in the second crop in the previous year, and it was proposed to use more seedlings and/or a closer spacing to discover whether a more satisfactory yield could be secured.

Experimental work had shown that 2 seedlings spaced at 12 in. gave the optimum yield for the first crop, and for the second crop a 4×4 Latin square was laid down to test the following treatments:

A	Control	2	seedlings	at	12-in.	spacing
B	,,	4	,,	,,	12-in.	,,
C	,,	2	,,	,,	9-in.	,,
D	,,	4	,,	,,	9-in.	,,

The seed was sown on October 5, 1948, and transplanted a month later. All plots flowered in 86–9 days, which corresponds with the results of the monthly plantings in Fig. 1, and harvesting was done at 148 days.

Plot yields were very variable and the analysis of variance showed no significant differences between treatments. There does, however, appear to be a definite trend in favour of more seedlings per unit area as the following average figures show (lb. per acre): A 1,690, B 1,970, C 2,110, D 2,200.

The straw to grain ratio averaged between 1·6 and 1·9, as compared with 2·5 to 3 for the main-crop planting. This is to be expected as the plant is flowering at an earlier date than it would flower when growing in its accustomed photoperiod, and has made less vegetative growth.

It will be necessary to repeat this trial with perhaps even more seedlings per unit area, but even if significantly higher yields can be secured it may not prove an economical practice, taking into consideration the increased cost of transplanting many more seedlings at a far closer spacing than for the main crop.

The other solution lies in securing varieties adapted to the season of the late crop; therefore all varieties available at the time were planted in duplicate plots for a second crop. These are the normal main-season varieties of Trinidad Nos. 1–6, and British Guiana Nos. 7–10 (Table 2).

TABLE 2. *Growth and Yield of Second Crops*

	Days to flowering	*Mean plot yield (lb.)*
1. Sahadaya . .	83	22·0
2. Bajerbong . .	83	19·5
3. Joya I . . .	81	18·0
4. Mootmaria . .	83	17·0
5. Kalaiaman . .	83	19·5
6. Joya II . .	81	18·5
7. No. 79 . . .	80	20·5
8. D 110 . . .	78	16·0
9. D 52/37 . .	78	17·5
10. Blue Stick . .	80	13·5

All varieties seem to react to the photoperiod in the same way as Joya, flowering some 3 weeks earlier than June sowings, with a corre-

spondingly reduced yield. Consequently further introductions have been made from Ceylon and India for trial in 1949 of varieties that are not season-limited, or are adapted to the season of the second crop.

Discussion.—Although this series of investigations was planned primarily to investigate the practical possibilities of growing a second rice crop under Trinidad conditions, results of wider interest have been secured. The existence of a photoperiodic response in some varieties of rice has been known for some time, but the majority of the studies have been carried out in sub-tropical or semi-temperate countries such as Japan, North India, and the U.S.A. Scripchinsky [2], using data from monthly plantings in Ceylon, first demonstrated the photoperiodic response in rices grown nearer the Equator, and his explanation has been confirmed by the work of Chandraratna [3]. The latter, besides showing the relationship between time to flowering at different planting-dates and length of day, also modified artificially the length of day and found considerable differences in time to flowering.

The present work done at a similar latitude to Ceylon confirms the findings of Chandraratna and demonstrates that Trinidad varieties of rice behave very similarly to the $5\frac{1}{2}$-months rices of Ceylon.

Neither Scripchinsky nor Chandraratna describes the effect of photoperiod on yield, but Beachell [4] and others have shown that reducing the daily light-period besides inducing earlier flowering also results in lower yields. It was not possible in the present investigation to test this by changing the light-period artificially, so that it cannot be assumed that the reduced yields were entirely due to changes in photoperiod. Leaching of minerals as the wet season progressed, interruptions in irrigation supply, inadequate pollination when atmospheric humidity was low in the dry season may all play a part. It may, however, be reasonably assumed that the reduced yield of the October-planted second crop is in no small measure the result of the photoperiod-induced earlier flowering and shorter life cycle of the plant.

Summary.—Only one crop of rice is normally grown per year in Trinidad and experiments were initiated to try to secure a second crop after the first had been harvested.

It was found that Joya, one of the standard main-crop varieties, is influenced by photoperiod, and it would appear that this is one of the main factors responsible for the low yields of the second crop.

Introductions are being made to try to secure a variety adapted to the photoperiod of the second crop.

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AGRONOMIC AND BREEDING RESEARCH ON RICE, OIL-PALMS, AND CACAO IN MALAYA

Pt. II. OIL-PALMS AND CACAO

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Oil-palms

THE oil-palm was first cultivated in Malaya in 1917, but the area under it did not increase rapidly until the period 1925 to 1933, when about 63,000 acres were planted. Since then the area has increased slightly to the present figure (1949) of 84,100 acres. All planting has been carried out on estates only.

Practically all the palms growing in Malaya are of the 'Deli' strain of *Elaeis guineensis forma dura*, and the general overall average yield for the country is about 15–18 cwt. of oil per acre per annum, though many good estates in 1941 were averaging well over this figure and approaching 25–30 cwt. per acre.

Before 1941 experimental and research work carried out by the Department of Agriculture was mainly directed along the lines of manurial and cultivation trials, selection and breeding, and investigations into improvement in factory technique and control. The results obtained up to 1931 were incorporated in a publication by Bunting, Georgi, and Milsum [1], and subsequent work appeared in various numbers of the *Malayan Agricultural Journal* up to November 1941.

Agronomic investigations.—The position in regard to manuring was reviewed and summarized in 1940 [2] and, briefly, this showed that on one of the more extensive inland types of soil in Malaya oil-palms yielding less than 1,500 lb. of oil per acre per annum gave economic responses to dressings of rock phosphate (4 lb. per tree), the effects of which took 18 months to appear and which lasted for a similar period. On these soils there appeared to be a lack of response by older palms to nitrogen and potash manuring. A recently published work by Chapman and Gray [3] indicates that the response in yield of oil-palms to either phosphate or potash manuring may be judged by the K_2O/P_2O_5 ratio in the fronds, a high value for the ratio indicating a likely response to phosphate and a low ratio to potash.

For several reasons manurial experiments on oil-palms have proved difficult to recommence since 1945, but certain experiments are now being laid down by the Department of Agriculture both at their own experiment stations and on estates. One such experiment is designed to determine the optimum rate of phosphate manuring and the effect of different methods of placement. Another is designed to test the effect on yield of normal dressings of potash and phosphate with and without the addition of magnesium. This follows a pre-war experiment, the results of which have just been published [4], which gave strong

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indications that the application of Patent Kali, a proprietary potassium-magnesium fertilizer, had beneficial effects on yield and also improved the general appearance of palms suffering from 'bronzing'.

On the agronomic side, Greig [5] in 1937 reported on an experiment from which he concluded that the epiphytic growths common on oil-palms were without effect on yield or on the incidence of stem-rot. In 1940 Lucy [6] reported on certain experiments designed to increase the rate of germination of oil-palm seeds and came to the conclusion that fresh pericarp-free seed planted in sand-beds gave very satisfactory results, i.e. 88 per cent. germination in 32 weeks. The same worker also published in 1941 [7] an account of an experiment designed to test the effects of clean-weeding, slashing of the natural undergrowths, and forestry conditions with selective weeding of the natural undergrowths. This experiment ran for 4 years and at the end of this period it was interesting to note that whereas the slashed plots had maintained a steady yield, the clean-weeded plots had shown a marked increase in yield during the second and third years, followed by an abrupt drop back to normal in the fourth year. The forestry plots showed a gradual decline in yield during the second and third years but had risen to normal by the fourth. Lucy was of the opinion that on the clean-weeded plots there had been a temporary addition of humus and plant-nutrients arising from the decay of the natural undergrowths when the area was first clean-weeded, but that with exposure and rain the physical structure of the soil steadily deteriorated, and he expected a further decline in yield in subsequent years. On the other hand, he attributed the decline in yield during the first 2 years under forestry conditions to the fact that the undergrowth was growing freely during this period with very little cutting back and was competing keenly for plant-nutrients. By the third year, however, when the undergrowth was firmly established and kept in check by frequent slashing, a considerable amount of nutrient material was returned to the soil in the form of leaves, twigs, branches, and undesirable plants, with a consequent gradual improvement in soil structure, nutrient supply, and crop yields. He expected that in subsequent years this improvement would be maintained. Most unfortunately the experiment was stopped at this point by the outbreak of war in Malaya and as yet it has not been found possible to repeat it.

Agronomic experiments that are being, or have been, conducted post-war are closely concerned with the practice of replanting. By 1946 many estates which had been planted before 1930 were experiencing considerable difficulty in harvesting the fruit at economic rates owing to the height which the palms had attained: most of the palms were producing fruit-bunches at nearly 30 ft. above the ground. Moreover, the original palms were planted from unselected seeds and varied considerably in yield. Between 1930 and 1946 selection work had produced some promising preliminary lines. There arose therefore in many cases the question of replanting with better material. With this object in mind experiments have been carried out recently on the felling and disposal of old oil-palms by poisoning and by mechanical methods, and full details of these and the costs thereof have been published [8].

Poisoning by sodium arsenite (1 oz. per palm) has proved very cheap and efficacious.

An experiment designed to show the best age to out-plant seedlings was commenced in 1938 and the seedlings were held 1, 2, and 3 years in the nursery-beds and then planted out. Results to date indicate that seedlings held for 3 years in the nursery suffer too severe a check on transplanting and subsequent yields are low.

A comprehensive replanting experiment is now about to be laid down with pedigree seedlings to test the time of planting in relation to the time of cutting out of old palms; various manurial treatments are included in the experiment.

Agronomic experiments in progress on certain estates are designed to ascertain the effect of mechanical inter-row cultivations on palms on different soil types. The treatments include combinations of slashing, light disk-harrowing, and chiselling.

Evidence is accumulating that oil-palms are tolerant of acid soil conditions. Palms planted before the war, replacing moribund coconuts on acid coastal clay and muck soils, have grown surprisingly well and are giving good yields. Laboratory experiments have shown that seedling oil-palms in nutrient solution grow better as the pH value is lowered from 6·5 to 3·5.

Selection and breeding work.—Selection work on oil-palms was started by the Department of Agriculture in 1921 and pedigree breeding began in 1929 with crossings of certain selected palms growing at the Departmental Experiment Station, Serdang. Progeny rows of seedlings resulting from these pedigree crosses were planted out in 1930, 60 progeny lines with 30 palms in each line, but this material has not proved to be of a very high standard.

About the same time, individual palm records for selection purposes were commenced by the Department on certain estates. Selections from one of these estates, on which records of individual palm yields and fruit characters were kept for 10 years, have proved more encouraging. Twelve selected palms, including the highest producers, were used for genetic studies; they were selfed and inter-crossed and the progeny was planted out at Serdang in 1937, 1939, and 1940.

Although at present the best of these families is not yielding above a ton of oil per acre per annum, it is felt that this yield figure has been influenced by the neglect which occurred during the war years, and by the general low level of fertility of the area in which the palms are growing. The figure compares favourably with that for adjacent non-selected material growing on similar soil. Two of the progeny lines, E. 211 and E. 268, have proved significantly higher yielders than the others, and E. 93 has shown a significantly high percentage of pericarp. Certain other progeny lines have proved abnormally susceptible to yellowing and 'bronzing'.

One of the original palms, E. 206, was of exceptional girth and small annual increment in height, and the selfed progeny have bred true in these characters. The average yields of palms in this line are on a level with most of the pedigree families. These palms are of particular

interest as the slow growth-habit favours easier harvesting and longer economic life. E. 206 has been crossed with selections of normal palms, but there is insufficient evidence as yet to state with certainty whether this quality of 'dumpiness' is a recessive genetic character or whether it represents an extreme expression of quantitative genetic factors for height and girth. The E. 206 palms bear bunches with an abnormally high proportion of parthenocarpic fruit, having only a rudimentary nut.

The present objects of breeding work are to continue the production of high-yielding palms with a high pericarp percentage of both the dumpy and standard types, and to eliminate, if possible, the partial sterility of the dumpy type. To continue this breeding programme, additional parental material is being sought from within Malaya and by importation from other countries.

Cacao

In 1947, apart from three small plots on Departmental Stations and a few isolated trees in native holdings, amounting possibly to a few hundreds only, there were, so far as is known, no cacao trees in Malaya. Early in 1948, however, a visit was paid to Malaya by Cheesman whose report [9] on the possibility of development of this crop in the country aroused considerable interest.

One or two small experiments on the growing of cacao had been carried out earlier by the Department of Agriculture without much success [10], and it was the remaining trees on these experimental plots that constituted in 1948 the bulk of the available planting material in the country. This material was of a Trinitario type and the best trees were considered by Cheesman to be sufficiently suitable for immediate expansion.

The interest aroused by the cautious optimism of Cheesman's report gave rise to immediate calls from estates for planting material, and likewise there arose a clear need for a series of agronomic experiments. The danger of the introduction of any of the common diseases of cacao ruled out any question of bulk importation of planting material, hence during the last two years efforts have been directed towards bulking the supply of material from local sources in order to provide enough material to plant as many experimental plots as possible on estates and Agricultural Stations. Certain limited importations, including Amelanado material from West Africa, are now being carried out by the Department under strict quarantine arrangements.

Experiments on methods of establishing cacao have been laid down since 1948 at 8 agricultural stations and on 21 estates. In general, an experimental plot is about 5 acres. The methods under investigations involve the use of primary shades (Tephrosia spp., Crotalaria spp., *Leucaena glauca* and *Cajanus indicus*), secondary shades (bananas or *Gliricidia maculata*), and tertiary shades (Albizzia spp., *Enterolobium saman*, and *Peltophorum ferrugineum*). Full details of these experiments have been published [11]. They have already indicated that where cacao has been planted between thickly sown rows of primary shades, 2 ft. either side of it, growth is not so good as where the primary shade is

thinner and the young cacao is protected by cut palm-fronds. Root competition and too heavy shading may both clearly be influencing factors.

Other types of experiments have been started on estates to test the effect of planting cacao with young rubber, coconuts, oil-palm, and Manila hemp. Cacao has also been planted under mature rubber and coconuts, but in these cases it has been found that unless isolation trenches are dug and constantly reopened, the rubber or coconut roots soon throttle the young plants.

Concurrently with these experiments, investigations are being carried out on the vegetative propagation of cacao [12] and considerable success has been obtained both in budding and in striking cuttings. Propagation bins of the Costa Rica type have been constructed to see if large-scale production of rooted cuttings can be effected.

On the recorded yields of mature trees growing on Departmental plots, 20 preliminary selections have been made and clonal trials from these trees have been planted out.

A comprehensive programme of selection and breeding has been started with locally available material, and the introduction of further types is now under consideration.

Acknowledgement.—This review has been prepared to a great extent from Departmental reports, published and unpublished. My thanks therefore are due to the authors of these many reports, and also to a number of officers who have proffered helpful suggestions.

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AN EXPERIMENT ON THE PRODUCTIVITY OF LEYS CUT FOR HAY

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ALTHOUGH it is a common practice in areas where ley farming has long been established to cut leys for hay in the first year, the statement is frequently made that haying in the first year is harmful to the subsequent productivity of the sward. It seems that the statement is based on observations, particularly of botanical make-up of swards, and not on precise productivity data. Garner and Sanders [1] drew attention to this deficiency and conducted two quantitative experiments on 4-year leys. In one experiment they found that haying in the first year did reduce the over-all 4-year yield, but another experiment gave precisely the opposite result. They suggested that where the plants were slow in establishing themselves and when the first harvest year was very dry, haying in that year was advantageous.

This paper records the results of a replicated experiment to study the effects of haying leys in their first, second, and third years. Incidental to this, an unreplicated comparison of leys derived from indigenous and from commercial grasses was made.

It must be emphasized that the results are for one experiment on one class of soil and that conclusions as to their general applicability cannot be drawn.

Experimental details.—One-half of a field was sown to 'commercial' seeds and the other half to 'indigenous' seeds. Sixteen $\frac{1}{4}$-acre plots were arranged on each seeds-mixture in 4 random blocks, allowing 4 replications for management treatments, which were:

G = Grazed only.
H1 = Cut for hay in 1st year and then grazed.
H2 = Cut for hay in 2nd year, otherwise grazed.
H3 = Cut for hay in 3rd year, otherwise grazed.

The seeds-mixtures used were:

Commerical	*lb./acre*
Irish Italian ryegrass	6
Irish perennial ryegrass	15
American cocksfoot	6
American timothy	5
English broad red clover	$1\frac{1}{2}$
English late-flowering red clover	$1\frac{1}{2}$
English S100 white clover	1
English wild white clover	$\frac{1}{2}$
	$36\frac{1}{2}$

Indigenous	*lb./acre*
Irish Italian ryegrass	6
S23 Perennial ryegrass	5
S24 Perennial ryegrass	5
S101 Perennial ryegrass	5
S37 Cocksfoot	3
S26 Cocksfoot	3
S48 Timothy	5
English broad red clover	1
English late-flowering red clover	1
S123 late-flowering red clover	1
S100 white clover	1
Wild white clover	$\frac{1}{2}$
	$36\frac{1}{2}$

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The field was previously down to cereals (1942–5) following a ley (1934–41).

The seeds were sown directly (broadcast) on September 17, 1945. Before sowing, 4·5 cwt. basic slag (17% P_2O_5) and 1·75 cwt. Nitro-chalk were applied per acre. In the spring of 1948, 2 cwt. superphosphate and 0·5 cwt. muriate of potash were applied per acre. Nitrogenous manuring was as follows:

Nitro-chalk (*cwt. per acre*)

	March	*April–May*	*June–July*	*September*	*Total*
1946. .	1	1	1	..	3
1947. .	1	1	1	..	3
1948. .	1	2	1	1	5

The plots were grazed rotationally by Dairy Shorthorn heifers aged 1½–3 years, and the intensity of stocking was arranged to complete the grazing of any one group of plots in 4 days or less. In 1946, 8 plots, comprising one management treatment, were grazed simultaneously. In 1947 the routine was altered to the grazing of one block on each of the mixtures simultaneously.

Small areas were cut by 'Autoscythe' on each plot prior to the entry of cattle to estimate the amount of herbage present (pre-grazing) and others on completion of grazing (residues); 4 random cuts (each 8 sq. yds.) were taken per plot at each grazing in 1946 and 6 random cuts (each 2 sq. yds.) were taken in 1947 and 1948.

Two sets of figures from the herbage data are used:

(i) 'Total growth.' This comprises the whole of the first pre-grazing cut (P_1) plus each of the subsequent pre-grazing yields less the residues (R) at preceding grazings, i.e. $P_1+(P_2-R_1)+\ldots+(P_n-R_{n-1})$. Total growth is thus an estimate of the new growth which occurred during a season.

(ii) 'Herbage consumed.' This is the sum of the pre-grazing yields less the residue yields, i.e. $(P_1-R_1)+(P_2-R_2)\ldots+(P_n-R_n)$.

Obviously none of the figures quoted is absolute, as defoliation by autoscythe is not identical with grazing; the figures are, however, comparative.

Hay yields were obtained by weighing 4 large random cuts per plot.

Records were kept of grazing days and in 1947 and 1948, following the installation of a weighbridge on the field, of the live-weights of the cattle used. It was assumed that consumption of herbage was directly proportional to live-weight. With the aid of a photographic record of each animal and fortnightly weighings, the number and live-weight of cattle per plot were arranged, as far as possible at random, so that the times taken to defoliate plots of a group were similar. As the cattle were on any one plot for only 4 days per grazing, it is obviously impossible to use live-weight changes to assess herbage production.

Full experimental data can be obtained on application to the authors.

Botanical composition of swards.—The botanical aspects are considered first because they are relevant to the interpretation of the data for yields and protein-content of herbage.

The 'take' of seeds was excellent. By November 1945 the ryegrasses were well established and clovers satisfactory. Cocksfoot and timothy were sparse. There was no noticeable difference between the commercial and indigenous swards.

During the 1945–6 winter the clovers lost vigour and owing to the cold, wet spring were late in getting going. From mid-season the clovers improved and by October constituted 25–30 per cent. of the sward. Cocksfoot did not get going in 1946.

In 1946 the ryegrasses were predominant. Obviously 6 lb. Italian ryegrass per acre was too much under the conditions. In the early part of the season ryegrasses contributed 80 per cent., but this fell as the season advanced.

The percentage composition of the sward at the end of 1946 was roughly: Ryegrasses, 40–50 (one-third Italian); timothy, 10; clovers, 25; agrostis sp., 5.

In 1947 the ryegrasses remained dominant, but there was a decrease in the proportion of Italian. Timothy increased to about 15 per cent. and cocksfoot made a small contribution. Clovers amounted to about 30 per cent.

In 1948 ryegrass was still dominant, but Italian had fallen to a negligible amount. Cocksfoot had increased to about 10 per cent. and timothy remained at about 15 per cent. The proportion of clovers was rather lower than in 1947, possibly owing to weather conditions being more favourable to the grasses.

The botanical composition of the hay crops is given in Table 1. It will be noted that the 1946 hay contained very little clover; the reasons are given above. The 1947 hay crop was very clovery; this may have been a reflection of the very dry weather.

TABLE 1. *Percentage Composition of Hay Crops*

	1946	*1947*	*1948*
Perennial ryegrass	37	25	51
Italian ryegrass	40	14	4
Cocksfoot	1	3	10
Timothy	7	13	13
Red clover	3	24	10
White clover		11	
Weeds and weed grasses	12	10	12

There was no evidence that cutting for hay depressed the clover-content of the sward in the next season or, for that matter, in the aftermath after haying.

'Total growth' of herbage.—The derivation of these figures is explained above; they are an underestimate in that they take no account of growth which occurred when the cows were on the plots.

The over-all average yields of dry matter per year from the 'commercial' and 'indigenous' leys were 50·99 cwt and 49·27 cwt. per acre, respectively. Thus, in this experiment, which lasted 3 years, the two types of ley gave practically identical yields of dry matter. In view of this the two are not further considered separately in this section; all figures given below are averages for the two types.

The average results per treatment are given in Table 2. The italicized figures refer to the year in which the hay crop was taken.

TABLE 2. *'Total growth' and hay: Cwt. Dry Matter per Acre*

	'Total growth' including hay					
	G	H 1	H 2	H 3	*Sig. diff.*	*Hay*
1946 .	54·50	*71·56*	54·64	49·62	4·2	38·90
1947 .	33·25	30·48	*38·67*	30·46	3·0	24·83
1948 .	64·02	60·35	54·84	*60·36*	5·2	35·15
Average .	50·25	54·13	49·38	46·75	..	..

As this experiment was not 'replicated in time' (i.e. separate experiments were not started in 1946, 1947, 1948, &c.) interpretation of the results is complicated by variations in weather from year to year. It so happened that 1946 was very wet, 1947 exceptionally dry, and 1948 about average.[1]

In 1946, the first year, the yields from G, H2, and H3 should have been similar, as all were grazed. The lower average yield of H3 cannot be satisfactorily explained. Two H3 plots suffered unduly from wetness in spring; this may have been due to subsoil variation. Later, these plots were indistinguishable from the other H3 plots. The hay crop was taken after grazing an early bite of 11 cwt. dry matter per acre.

In 1947, a very dry year, the H1 grazing yield was not significantly less than G or H3; thus the removal of a 2-ton per acre crop of hay in 1946 did not affect herbage production in 1947. Owing to the very late spring, grazing before closing for hay was deemed inadvisable in 1947.

In 1948 the grazing yield on H2 (hayed in 1947) was significantly lower than G and H1, i.e. haying in the *second* year reduced growth in the *third* year. One can only speculate on the reason; the abnormally dry weather in 1947, when H2 was hayed, may have resulted in serious depletion of root-growth, which was not made good later in the season. The H3 hay crop in 1948 was taken after grazing an early bite of 15 cwt. dry matter per acre.

Perhaps the main conclusion to be drawn from the results as a whole is that it is dangerous to generalize. Clearly in this experiment the statement that haying a ley in its first year is harmful has not been borne out. This is in line with the results obtained by Garner and Sanders (loc. cit.) on a ley that established well and when the first harvest year was not dry; it is in contrast with their results on a poorly established ley when the first harvest year was exceptionally dry. The

[1] Rainfall for April–September: 1946, 17·68 in.; 1947, 8·00 in.; 1948, 12·12 in.

results show, however, that haying in the second year, which was very dry, reduced herbage production in the third year. How widely this result applies can only be speculated upon; it is more likely to apply in south-east England than in the wetter north-west.

Taking a hay crop, even an early one, tends to suppress clovers, and this effect is likely to be most marked in the first season when the clovers, particularly white clovers, are getting established. In the present experiment the clovers germinated well in 1945 but suffered badly in the cold, wet weather of the winter and early spring. As a result, clovers made little contribution to the 1946 hay crop. If the ley had been clovery early in 1946, haying in that year might have reduced the amount of clover present in 1947; whether this would have reduced dry-matter yields in 1947 is an open question. The fact that clovers on the plots hayed in 1946 had increased from almost nil to 25 per cent. by the end of 1946 and to 30 per cent. in 1947 is evidence against the argument that having a clovery sward in 1946 would have reduced clovers in 1947.

Protein-content of herbage.—Since all plots received the same amounts of fertilizer, and as in any one year 3 out of the 4 management treatments were identical, the work involved in analysing for protein-content all samples taken was not considered justified. Average protein-content was obtained from bulked samples per plot on a number of occasions. A summary of the figures is given in Table 3.

TABLE 3. *Protein-content of Herbage* (*percentage dry matter*)

		Herbage grazed	*Hay*
1946	April	9·4	
	June–July	8·3	5·6
	September–October	17·0	
1947	May	14·9	
	June	12·3	10·7
	July	13·3	
1948	April	13·1	
	May	13·4	
	July	13·0	7·4
	August	13·6	
	September	14·5	

The protein-content of the herbage grazed was, as a whole, low as judged by milking-cow requirements. In 1947 and 1948 protein was adequate for the class of stock used. In 1946 it is possible that the cattle were not given enough protein early in the season.

Among the possible reasons for the rather low protein-content are that nitrogen-fertilizer usage was only moderate and that growth was often rather advanced when grazed. When growth is rapid some herbage is bound to get a little too long in experiments of this type unless a very large number of cattle are available to graze all the plots at the optimum stage.

The protein-content of the hay crops is related to clover-content:

	Protein %	*Clovers* %
1946 . . .	5·6	3
1947 . . .	10·7	35
1948 . . .	7·4	10

The leys were ryegrass-dominant, and we know from other experiments that ryegrass hay can be very low in protein if not generously dressed with nitrogen fertilizers. To avoid complicating the issue, late top-dressings were not applied to the hays to increase their protein-content; it is probable that if late top-dressings had been applied in 1946 and 1948, the protein-content of the hays would have been considerably higher.

The average protein-content for the commercial and indigenous mixtures was:

Crude Protein in Dry Matter, %

	Herbage grazed		*Hay*	
	C	*I*	*C*	*I*
1946 . .	11·8	11·3	5·6	5·6
1947 . .	13·7	13·1	10·6	10·7
1948 . .	13·1	12·5	7·3	7·5

C = Commercial. *I* = Indigenous

There was clearly no difference in protein-content between the two types of seeds-mixture.

Utilization of herbage.—From the herbage data, which it must be remembered are comparative and not absolute, figures for percentage apparent utilization of herbage by the cattle can be estimated. These are given in Table 4.

TABLE 4. *Apparent Utilization of Herbage*

	Cwt. dry matter per acre			*Apparent utilization* %	
	A	*B*	*C*		
	Total growth	*Sum of pre-grazing*	*Consumed*	*100C/A*	*100C/B*
1946	54·5	59·6	48·0	88	81
1947	32·2	40·6	27·2	84	67
1948	64·7	79·0	59·2	91	75

The figures in column *A* refer to new growth during the season, those in column *B* to the sum of the pre-grazing cuts (i.e. total herbage presented including residues left after previous grazings), and those in *C* to the differences between pre-grazing and residue cuts.

In the past it has been usual to quote utilization in terms of *C/B*, i.e. ratio of herbage consumed to total herbage presented, including

residues from previous grazings. In this report utilization is also expressed as $100C/A$, i.e. utilization of new growth, assuming residues from previous grazings remain uneaten and, in effect, accumulate as the season advances.

Both sets of figures show that utilization was lower in the dry year 1947 than in 1946 and 1948; we assume that soiling of herbage was more marked and ryegrass more stemmy in mid-season in the dry year.

The figures $100C/B$ are a little high compared with those obtained when milking-cows are used. This is probably because the aim was to try to keep residues down to a reasonable minimum, which no doubt meant that on occasions the dry cows were kept on the plots longer than would have been possible with milking-cows without the milk-yields falling.

From the figures for grazing-days, cattle-weights, and estimates of herbage consumed (pre-grazing minus residue cuts), the apparent daily consumption of dry matter per 112 lb. live-weight can be calculated. The figures are given in Table 5. The over-all mean of 2·24 lb. dry matter intake per 112 lb. live-weight is based on more than 300 recordings.

TABLE 5. *Lb. Dry Matter consumed daily per 112 lb. Live-weight*

	Mean of all grazings	*1st grazings only*	*3rd or 4th grazings*
1946* . .	2·23	2·48	1·62
1947. . .	2·27	2·48	1·25
1948. . .	2·21	2·43	2·07
Mean . .	2·24	2·49	1·65

* Live-weights assessed by eye

The figures show that consumption of herbage was considerably higher early in the season than later; we believe the reasons to be that later in the season a good deal of herbage was soiled and unpalatable, and that the ryegrass tended to be stemmy. The lowest consumption was in late 1947, the very dry year, when droppings would be maximal in soiling effect.

Acknowledgements.—A. H. Green was responsible for the conduct of the experiment in 1946 and 1947. The field work in 1948 was done by A. E. M. Hood.

Summary.—An experiment to study the effects on the productivity of leys of cutting them in their first, second, and third years is described. Incidental to the main purpose was a comparison of leys derived from leafy indigenous and from commercial seed.

The results are for one experiment only and conclusions cannot be drawn as to their general applicability.

The results show that cutting a ley in its first year did not reduce its output in succeeding years. It can therefore be concluded that the statement that a ley should not be cut for hay in its first year is not

always true. Whether it is usually true we do not claim to know; we have no data to prove it, and the fact that cutting for hay in the first year is common practice in areas where leys have long been used suggests that if any harm results it must be small.

The results show that haying in the *second* year reduced output in the *third* year. It so happened that the second year, 1947, was abnormally dry, and it may be that haying resulted in seriously depleted root-growth which was not made good later in the season. The significance of this result can only be speculated upon; it is possible that haying any grassland in any year may depress production in the next year if the plants cannot develop a good root-system in the autumn after haying.

It is important to note that the reduced herbage production in the third year following a hay-cut in the second year was not due to suppression of clovers.

In this experiment there was no difference in productivity between indigenous and commercial leys.

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THE INVESTIGATION OF WET SOILS AND ITS AGRICULTURAL IMPLICATIONS

W. H. PEARSALL

THE world-wide need for increased agricultural production may well justify the re-examination of the properties of wet soils with a view to their greater utilization in agriculture and forestry. The only extensive form of agricultural cultivation on wet soils is that of rice. Thus the scientific treatment of rice-crops depends largely upon the knowledge of the soil systems involved, and this knowledge has recently been advanced by ecological studies to a point at which it may be profitable to turn and consider the manurial problems of this specialized crop in the light of recent advances. In this paper recent ecological work on aquatic and marsh soils is described and the conclusions drawn are considered in relation to the manurial problems involved in rice cultivation.

Soil aeration.—The problems of wet soils are almost entirely bound up with the fact that they are liable to lack oxygen owing to their high water-content, the amount of oxygen or air in a given soil being roughly inversely proportional to the water-content. In practice the problem is to determine the boundary at which properties of any soil are determined by the effective presence of oxygen or its absence. We require to know not so much the absolute values of the oxygen as whether it affects the life in the soil so as to produce oxidations. In the extreme cases it is easy to distinguish well-aerated or *oxidizing* soils from waterlogged or *reducing* soils.

The boundary.—The borderline between sufficient oxygen and deficient oxygen occurs at low oxygen concentrations and it is not easily measured in the field because any disturbance of the soil, necessary for measurement, is bound to increase the oxygen-content. It has proved practicable in moist soils to get an indication of the effective oxygen concentrations by measuring what is usually termed the oxidation-reduction potential, sometimes the 'redox' potential. This in practice is the electrical potential recorded when a bright platinum or gold electrode is inserted into the moist soil; and the E.M.F. at this electrode is compared with that produced by a suitable standard. (For details of procedure see particularly [1, 2].) Two practical points are important: the electrode must be inserted with as little disturbance as possible to avoid allowing air (oxygen) to enter, and it will then take 10 minutes, often more, to give a steady reading. In the presence of oxygen the potential recorded at such an electrode depends mainly on the oxygen concentration present and also on the chemical characters of the soil (particularly when the oxygen is very low).

Since the magnitude of the potential is greatly affected by the acidity of the medium, rising as acidity increases, allowance has to be made for the soil pH. In northern England, where much of this work was done, the average pH is near 5, so that this was taken as a base-line for comparing estimates of soil potential. At this pH, normal well-aerated soils

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would have potentials of above 0·5 volt, whilst for waterlogged soils the potential would be below 0·3 v. The corresponding figures at pH 7 would be about 0·4 v. and 0·2 v. It is easy to show the dependence of these figures upon oxygen concentration by increasing the water-content of a well-aerated soil or by admitting air to a waterlogged one. In either case the potential drifts on treatment towards the values of the alternative type.

The observations on soil redox potentials proved to be very useful when they were considered in relation to other soil properties, and particularly those of microbiological character.

Field tests.—The soil organisms characteristically convert organic matter to different products in the presence and the absence of oxygen respectively. In decay under anaerobic conditions, marsh gas (methane) or methyl compounds replace carbon dioxide; ammonia replaces nitrates; sulphides like sulphuretted hydrogen replace sulphates; and at times phosphine replaces the soil phosphates. The first three of these are all useful and easily detected indicators of biologically effective anaerobic conditions.

In practice, two other tests became equally useful. In the earliest field observations the diphenylamine test was used to detect nitrates in soil extracts. It was observed at an early stage that the test was valid only for nitrates in the absence of soil. Particles of natural soils, especially those of the more organic types, may give a strong blue coloration with diphenylamine and sulphuric acid even though nitrates are absent. This indicator is in fact an oxidation-reduction indicator that gives a colour in the presence of soil oxidants other than nitrates.

We used also as a field test Comber's reagent, alcoholic ammonium thiocyanate, which gives a red colour due to ferric ions on shaking with lime-deficient soils [3]. Of course, with this test, no reaction is given at first with wholly anaerobic reducing soils however base-deficient they may be, because the iron is present in the ferrous state. In such a case a colour may develop on standing in air or, more quickly, on adding a drop of hydrogen peroxide, when the ferrous iron is oxidized to ferric iron. Here then is a simple and direct method of finding out the state of the soil iron compounds whether oxidized or reduced.

These various tests can all be used to tell us the same thing, whether the soil is effectively *oxidizing* or *reducing*, and it proved almost always possible to find out in the field by such simple means which of these conditions existed in a given soil. When the results of such tests were compared with the potential readings, it was found that reducing conditions were invariably present below a potential of 0·3 v. at pH 5, whilst oxidizing conditions were associated with potentials of 0·35 v. and upward. The most generally useful tests are those for ammonia or nitrate and for ferrous or ferric iron. In mineral soils (as is well known) the soil colour often serves to indicate oxidizing or reducing conditions, but most of the work described here has been done with soils strongly coloured with humus or peat. The field tests showed also that earthworms are, as one might expect, indicative of oxidizing conditions; indeed, any appreciable visible evidence of a soil fauna is indicative in

this respect with the exception of certain Donacine beetle larvae, which can exist in anaerobic conditions by tapping the roots of aquatic plants for oxygen. Generally speaking, trees are absent in Britain from reducing soils, though certain shrubs, particularly *Salix atrocinerea*, can survive on them. Alder and the larger willows grow on soils that are reducing only at some seasons and for a limited period.

The detailed relations between the electrical potential and other properties have been examined much more closely in oxygen-deficient lake-waters and aquatic muds [4]. In water one can, of course, use indicator methods of studying the oxidation-reduction potentials, and with their aid it is possible to be much more precise in detecting dissolved substances and also in estimating oxygen concentrations. In developing this line of attack Mortimer [5] devised apparatus by which sufficiently large, and therefore stable, samples could be collected and taken to the laboratory for precise study. The developments of technique in this way have enabled him to show that in oxygen-poor lake-water and lake-muds the various oxidation-reduction reactions mentioned above take place at somewhat different ranges of potential. Thus, in muds, the nitrate to nitrite reaction centres round 0·45–0·40 v., nitrite to ammonia 0·40–0·35 v., ferric to ferrous iron 0·3–0·2 v., and sulphate to sulphide 0·10–0·06 v., the measurements being at pH 7. The possibility also exists that these changes are not always simply microbiological reactions but are catalysed by the complex humus compounds present. Some of the changes in lake-water are extraordinarily sensitive to small traces of oxygen, and this is especially marked in the transformation of these compounds containing ferrous iron. The conversions of nitrogen and sulphur compounds take place much more slowly and sometimes seem to depend on the state in which iron is present.

Rate of change.—In most places the commonest type of wet soil is one that becomes waterlogged only at intervals as, for example, during a rainy season or owing to natural floods, or irrigation. If such a soil contains organic matter and/or is in any way microbiologically active, waterlogging will be followed by disappearance of oxygen and the soil will become reducing.

In the examples of marsh soils of this type that have been studied, the rate at which this change-over takes place on flooding varies considerably. Other things being equal, it depends on the amount of organic matter present; it is more rapid when this is higher. But in some base-deficient peats the rate of change is low, and in practice it seems to fall off also when the C/N ratio of the organic matter exceeds 20. In general then, the rate of change is always higher in base-saturated soils and becomes low in highly base-deficient ones. Finally, the rate of change varies in parallel with features of vegetation. Any soil that is productive (as shown by the large size of its natural vegetation) is likely to exhibit rapid changes of redox potential on flooding.

A second point of interest is that the conversion of an oxidizing soil to a reducing one greatly increases the availability of mineral ions in the soil solution. The conversion of ferric to ferrous ions means a change

from metallic compounds which are nearly insoluble at ordinary ranges of acidity to those which are freely soluble. The ferrous ions are also bivalent and more freely exchangeable on the soil colloids. Similar considerations apply to manganese. Finally, the production of ammonia instead of nitrate from decomposition of organic matter also leads to base-exchange by which bivalent ions especially, e.g. Ca, Mg, and Fe, are freed to the soil solution. Thus important differences are observed in the base-exchange properties of a marsh soil according as it is in the oxidizing or reducing condition. These are illustrated by the following analyses of samples of a rather peaty soil taken in July (oxidizing) and January (waterlogged) from the same square-metre quadrat. The soil samples were treated on the site with *N*. ammonium chloride solution to extract exchangeable bases.

Exchangeable Substances in a Marsh Soil (1938–9) as mg. per 100 gm. of Dry Soil

	pH	*Ca*	*Mg*	*Fe*	*Mn*	*Al*
July, oxidizing condition . .	5·53	242	27	3	0	4
January, reducing condition .	5·67	279	59	248	19	8

The figures show in a striking manner how the completely waterlogged condition is associated with increased proportions of exchangeable ions, especially of iron and manganese. Similar data are available for deep-water muds from lakes [5]. In this case, as oxygen disappears and the oxidation-reduction potential of the mud-surface falls to the critical level, the ion-content of the supernatant water greatly increases, as is shown by its greatly increased conductivity, and finally both the silica and the phosphate of the water increase. Thus the development of anaerobic or reducing conditions at the mud-surface greatly increases the solubility of many of the elements required for plant nutrition and in lake-muds evidently plays an important part in replenishing the productivity of the lake-water for the growth of algae. It is probable that equally important nutritional effects may result when oxidizing soils are submerged or swamped and become reducing, or even when a soil develops a reducing zone within easy reach of its surface. Of course, plants able to exist under such conditions must be present to make use of such conditions of increased ion availability. These plants must resemble marsh plants in having internal air-spaces in their roots, so that the root-tissues can grow and function without an external supply of oxygen. Rice appears to be almost the only crop-plant of this type.

Under most conditions, differences in oxidation-reduction potential can be observed not only in the same soil at different seasons but also by studying the depth-zonation of a wet soil. There will normally be a surface oxidizing layer and below it a reducing zone. In lake-muds and in submerged marsh soils the oxidizing layer may at times be only a millimetre deep; it is a thin film of ferric-humic deposit and often

from 1 to 10 cm. deep. One cannot, however, assume that this is always so in recently flooded soils. In salt marshes, lying within the upper part of the tidal range, for example, flooding comes only during the spring tides. At its onset the marsh soils are well aerated and oxidizing to a considerable depth. Flooding from the sea produces a waterlogged layer at the surface and an aerated zone below it. In this case the reducing zone develops in the surface-layers, its appearance there being favoured not only by the presence of much humus in the upper layers but also by the fact that these layers in such a marsh are often more clayey and less permeable than those below. In this case all the soils are base saturated and the pH is 7·5–8·0. Nevertheless, ferrous iron is formed and diffuses downwards. It is oxidized at the junction of the oxidizing and reducing zones and is precipitated as a reddish-brown 'pan' layer, which contrasts markedly with the upper black reducing zone. The soil profile is then a thin surface oxidizing layer with a black reducing zone just below it for a foot or more. Then comes a 'pan' of ferric iron and humus and a brown oxidizing layer of sandy soil below.

Development of waterlogged soils.—The trends of development in waterlogged or reducing soils are most easily seen and are least complicated in lake-muds, where they are marked by the gradual accumulation of organic matter. By the time this has reached about 20 per cent., the mud normally becomes extremely active in the microbiological sense, typically black, and strongly reducing with an abundance of exchangeable bases. Moreover, any appreciable oxidation will be unlikely below the surface film of 1 mm.–1 cm. deep.

The black colour is associated with the presence of ferrous sulphide and with a luxuriant flora, e.g. of pond-weeds (Potamogeton spp.). Such a soil continues to lose minerals freely by leaching, apparently owing to accumulation of ammonia and further base-exchange. A second stage of development can be recognized in which the organic-content is much higher (say 30–40%) and submerged vegetation sparse. The apparent sterility is associated with the presence of iron-tolerant plants (e.g. *Sparganium minimum* and *Potamogeton alpinus*) and often with the liberation of large amounts of methane. A still later stage of development has been observed in which hydrogen sulphide or methyl sulphide can be detected, and in this case the soil appears generally to have little or no vegetation. It is assumed that this represents an extremely leached type with little or no exchangeable iron, for example, and, indeed, one that is often peaty. It has not, as yet, been thoroughly studied but finds an obvious counterpart in the degraded Japanese soils described later.

Acidity.—Another feature of waterlogged soils that is best examined from the standpoint of development is that the lake-muds mentioned above are never very acid, even though peaty and base-deficient. The extreme range of pH found by Misra [6] for lake-muds lay between 5·4 and 7·2 (measured in 1 : 2 soil water suspensions saturated with quinhydrone). Similar measurements on bog soils, base-deficient peats for which there is evidence that they are probably permanently waterlogged [7], give values of 4·7 and upwards. These figures should be

compared with similar ones for *oxidizing* soils in northern Britain, for which the pH range is 2·8–8·0. Moreover, when reducing soils of the types just mentioned are exposed to air they rapidly become more acid, a change that is at first reversible (e.g. on re-flooding). In the same manner, base-deficient and reducing peats in nature usually become extremely acid when drained and maintained for some months or years in the oxidizing condition. The changes involved here appear to be finally irreversible, although if a high degree of aeration is maintained complete decomposition of the peat may ultimately take place. In the same way, base-deficient and reducing bog-peats generally give rise to extremely acid peats on draining. Although a completely satisfactory solution of this problem has not been obtained, it does seem from the preceding and other similar lines of evidence that the high exchangeability of bases under reducing conditions is important in maintaining the high pH of such permanently waterlogged soils.

Aeration, colloidal structure, and acidity.—Aeration of a waterlogged soil may have very marked effects on its physical structure. It is noticeable that when sub-aqueous muds are exposed to air they rapidly lose their semi-liquid nature, the sols present being precipitated in a few minutes. This change appears to be associated with the precipitation of iron-humus compounds, and also with a reduction in the total exchange-capacity. When peaty, reducing soils are aerated, similar changes no doubt ensue, but there are also slower changes in the structure of the humus colloids. These are irreversible and result in the formation of a colloidal structure which has more strongly acid properties in the sense that its dissociation constant falls in a lower pH range. It is also, apparently, microbiologically inert. Drying or extreme aeration is thus likely to produce harmful results in wet soils.

Nitrogen conversion.—The final points of interest concern the conversions of nitrogenous matter in wet soils. It is noteworthy that the badly aerated soils examined contain bacteria that break down organic matter to give ammonia, although fungi are apparently not able to act in this way in the absence of oxygen (H. Tristram, unpublished results). The ammonia thus produced accumulates in reducing soils but may be oxidized to nitrate when oxidizing conditions set in. The reaction takes place at the surface of the soil particles and depends on the concentration of absorbed ammonia. In most of the wet soils examined the reactions

$$\text{ammonia} \rightleftharpoons \text{nitrite} \rightleftharpoons \text{nitrate}$$

are reversible, depending on the oxidation-reduction potential, as already suggested. In addition to these changes, nitrates, nitrites, and ammonia can all be degraded to gaseous nitrogen which is lost to the air. This reaction is known to be induced both by bacteria and by certain algae. It is associated with the formation of nitrites and is most rapid (if not mainly confined to) reducing and acid conditions [8, 9]. Thus the C/N ratio of wet acid soils tends to remain high. The losses of nitrogen induced in this way are serious and are often accompanied by toxic effects due to nitrites [10, 11], but they are often balanced by the activities of nitrogen-fixing organisms, particularly in soils that are

only slightly acid. In highly acid soils, even if nitrogen-fixing types of bacteria occur, they are apparently represented by ineffective strains. In slightly acid and neutral soils nitrogen-fixing algae may be present. These are mainly blue-green algae. Luxuriant growths of these organisms occur in tropical waters and they are especially active under alkaline conditions. A part of their value lies in their ability to excrete nitrogenous substances to the surrounding water [12].

Swamp soils and rice growing.—The chief agricultural interest of these facts arises from the possibility that they can be made use of in increasing the productivity of wet soils. In practice the principal crop-plant grown on soils of this type is rice, so that it may be useful to consider some of the rice-growing problems in the light of the information about natural soils.

During the periods when it is submerged or waterlogged a rice soil develops reducing conditions, even though the surface-layer remains oxidizing as long as it is in contact with air or oxygen-containing water. It is therefore common to see a rusty-coloured surface-layer and a blue or blue-mottled soil below whenever the lower layers are exposed. Japanese workers have experimentally confirmed the existence of oxidizing and reducing zones, the depth varying probably with the duration of flooding and other similar conditions.

When a fertilizer like ammonium sulphate is sprinkled on a rice-field, it is affected by the conditions present in the surface or oxidation layer, the sulphate radical remains unchanged and the ammonia is converted to nitrate as in a normal soil. If, however, any part of this nitrate should pass into the lower reducing zone, it is reduced to nitrite and thence to atmospheric nitrogen, which is lost. It has been stated that as much as 70 per cent. of the nitrogen applied as ammonium sulphate may be lost in this way, not by leaching. The mechanisms by which the nitrogen is lost are almost certainly of microbiological origin [8].

If, in contrast, ammonium sulphate is trodden or worked into the lower zones of a wet rice soil, the ammonium ions remain unchanged in the reducing zone and are available to the growing crop. Marsh plants like rice have roots that are able to grow and function in reducing soils because they contain internal air-spaces, which carry oxygen internally to the respiring cells and growing tissues. Roots of this type often have round them a red-brown oxidizing zone and in some cases traces of nitrates have been detected in this 'rhizosphere'. It may also be mentioned that rice roots raise the oxidation-reduction potential of unaerated solutions.

Alternative nitrogen fertilizers.—It will be clear from the above that the success of any particular types of fertilizer will depend partly on the method and place of application. In general, nitrates should be applied only to the oxidizing zone at a time when immediate uptake by the crop is possible. Nitrate that penetrates to the reducing zone is generally lost. Ammonium nitrate has the particular theoretical disadvantage that in contact with reducing conditions it is readily reduced to ammonium nitrite, which may be converted microbiologically to gaseous nitrogen with great ease [9]. Calcium cyanamide has also been tried as a source

of nitrogen for rice. When it is applied to the surface-oxidizing soil it is acted on (presumably by micro-organisms), and is almost quantitatively converted to ammonia in from 5 to 7 days. It can then be mixed with all layers of soil. The best crop yields are obtained by this method. If the cyanamide is mixed with the deeper reducing layers at the time of application, it causes serious damage to the plants, so that it is not very effective in increasing the yield. Apparently the organisms converting it to ammonia require oxygen. An organic material like bean-cake is, however, quite effective when applied in the deeper layers. Presumably it is partly broken down to ammonia by anaerobic organisms and retained in the reducing zone in this form.

Sulphur.—It must be assumed that ammonium sulphate produces other effects besides those due to ammonia utilization. For example, when ammonium ions are absorbed, sulphuric acid is left and the soil solution may become extremely acid. This must accelerate leaching effects. When ammonium sulphate is added to the reducing zone the sulphate will be reduced to sulphide, which will combine with iron as long as that metal is available, but when iron becomes deficient, hydrogen sulphide or methyl sulphide will appear, both producing toxic effects on the crop-plant. It would seem that as long as the soil is saturated with calcium or iron the toxic effects are likely to be small.

Aki-ochi.—The effects due to sulphur are of particular interest in their bearing on the condition known in Japan as *aki-ochi* (literally 'fall-down') that affects as much as 20 to 40 per cent. of the crop under conditions of intensive cultivation. The condition is clearly associated with degraded soils from which Fe and Mn, as well as Ca and Mg, have been leached [13]. The parent soil type is obviously a contributory factor, as leaching must be most rapid in porous and somewhat sandy soils. It seems evident in the light of what we know of reducing soils that treatment with ammonium sulphate may accentuate the development of such a leached condition. Ammonia will free metallic ions from the soil by base-exchange. These bases could then leach away. This effect will be accentuated by the acidity resulting from the free sulphate ions. The development of reducing conditions subsequently will not only convert Fe and Mn into the reduced and soluble forms, facilitating leaching, but will also lead to the appearance of sulphides with possible toxic effects.

It looks as though calcium cyanamide might be a much better fertilizer than ammonium sulphate in the long run, as it would yield on microbiological treatment under reducing conditions three substances capable of maintaining the soil base-status—calcium, methyl radicals, and ammonia. No doubt this could also be said of suitable forms of organic manure.

Remedies.—Remedial treatments for the aki-ochi condition are at present largely based on the supposition that it is due to iron and manganese deficiency. Thus the layers of accumulated iron below the leached surface soil are mixed with the surface-layers. Red earths from adjacent hill-sides or mud from lakes or rivers are added in large

amounts, these serving as sources of the missing soil bases. I understand, however (W. E. Blewitt *in litt.*), that recent work in Japan has shown that the rice varieties most resistent to aki-ochi are those absorbing more manganese or silicon, or taking in less sulphur. Varieties with a high calcium uptake were also more resistant.

Liming and fertility.—An important factor in maintaining high productivity in rice soils is the base-status and pH of the soil. T. Harada [13] in Japan has found that dressings of slaked lime or other strong alkali like sodium carbonate are more effective than calcium carbonate. The dressing is needed in amounts large enough to raise the pH to 8·5 or 9·0. This results in a greatly increased—a fourfold—production of ammonia. It should not be overlooked that in British peaty soils bacterially controlled decompositions yield amines in acid media, but ammonia in alkaline soils; the former tend to remain in the soil complex, the latter is available for plant growth. The increased rice yields (*c.* 10%) associated with this very heavy liming have been maintained unchanged for as long as 8 years [13]. If this is generally true it appears likely that there must be a considerable amount of nitrogen-fixation, which is known to be favoured by an alkaline medium.

In India Fowler has commented upon the fact that though enormous quantities of organic nitrogen are removed in the rice crop, the use of nitrogenous manure is unusual. According to De [14] this is due to nitrogen-fixation, and in this case is associated mainly with the presence of blue-green algae on the soil surface or floating in the irrigation-water. Various workers have shown that nitrogen-fixation is frequent among blue-green algae.

The nitrogen-fixing activity of the blue-green algae is, however, greatly reduced in the presence of combined nitrogen, as in ammonia and nitrate, substances used in manurial treatments. Thus it would be profitable to work out cultural conditions which would enable the capacity of these algae for nitrogen-fixation to make its maximum contribution to the soil.

Singh has recently (1950) drawn attention to a cultural method of a suitable type. In the alkaline *Usar* lands of India, blue-green algae appear in abundance on the soil surface immediately after the first showers of the rainy season. If the soil becomes waterlogged, these algae form a floating mat in the water, and as a result of their growth it is stated that the organic matter and nitrogen in the surface soil can be increased by as much as 30–40 per cent. Singh therefore advocates the enclosure of small areas by embankments to allow of soil fertilization in this manner. It would be practicable to treat soil in this way two or three times a year, and the method is evidently one that could be applied equally well to rice-fields.

The whole of this subject presents features of interest because it constantly requires unconventional methods of thought and inquiry. Wet soils vary so much in the degree and season of wetness that it is evident that each example probably requires individual consideration. Nevertheless, there are three main points on which general principles are slowly emerging. These are the effects of oxygen-lack and high

water-content on the exchangeability of soil minerals, the character of the soil organic matter, and the availability of nitrogen.

It will be evident also that there may be considerable differences between the wet soils in different countries. Those in Britain are often highly organic and this colours the ecologist's or pedologist's outlook. In Japan, in contrast, the typical rice soil seems to be largely inorganic—perhaps almost to the point of starvation—and so mineral rather than microbiological effects seem to be most studied. No doubt it is the high temperature and the resultant highly rapid biological activity that has led Indian workers to stress the importance of the microbiological element in soil fertility, a point of view that is equally fruitful in Britain.

Acknowledgement.—It is a pleasure to acknowledge the debt that this paper owes to Mr. W. E. Blewitt. The comments on eastern rice-growing are largely based on his reports.

Summary.—The properties of wet soils depend mainly on their scarcity of oxygen. The boundary between soils with sufficient oxygen (oxidizing) and those deficient in oxygen (reducing) occurs in a characteristic range of electrical potential, in which also the chemical and biological characters are altered. Soils in the reducing state liberate larger amounts of exchangeable cations particularly iron, manganese, and aluminium. The pH range of permanently waterlogged soils is small even for non-calcareous lake muds, e.g. pH 5·4–7·2, and the colloidal properties are also affected. These effects run parallel to corresponding biological changes (e.g. nitrate or ammonia—sulphate or sulphide—carbon dioxide or methane). The bearing of these results on the properties and manurial treatment of rice soils is considered.

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INDEX

Altona, R. E., *see* Hall, T. D.
Armstrong, R. H., *see* Thomas, Brynmor.
Arthur, D. R., *see* Edwards, E. E.

Bald, J. G., testing and maintenance of potato clones, 95–104.
Barnett, A. J. G., preliminary experiments with a small-scale silo tower, 129–36.
Beef production in southern Africa, 81–94; Basutoland, 87–8; Bechuanaland, 88–90; Portuguese East Africa, 86–7; promising pasture grasses, 90–2; South-West Africa, 84–5; Southern Rhodesia, 85–6; Swaziland, 87; Union of South Africa, 82–4.

Cacao in Malaya, 279–80; methods of establishing, 279–80; mixed planting, 280; vegetative propagation, 280.
Cereal crops, effect of plant-growth regulators on, 19–30, 169–76.
Cereal crops, inflammability of, in relation to water-content, 150–62; field tests, 150–1; laboratory tests, 151–4; water-content: relation to climatic factors, 157–62, variation during ripening, 154–7.
Child, Reginald, recent research on the coconut palm with special reference to Ceylon, 177–89.
Chittenden, R. J., the Prang Besar (Malaya) experiments in the selection and propagation of Hevea, 105–11.
Clowes, G. J., *see* Hallsworth, E. G.
Coconut palm, recent research on, with special reference to Ceylon, 177–89; coconut products, 186–7; effect of cover crop, 185; genetics, seed selection, and germination, 180–2; manuring, 182–5; pests and diseases, 177–80: bud-rot, 179; insect pests, 177–8; nut-fall, 179–80; 'tapering', 179.
Cows, dairy, constitution and milk production of, 57–9; correlation between average milk production and age, 58–9.
Cows, dairy, in New Zealand, grazing habits of, 249–63; factors studied: environment-inheritance interactions, 259–60; 'herd laws', 260–2; individuality, 257–9; quantity and quality of pasture, 255–7; rhythms: diurnal, metabolic, seasonal, 254–5; technique and materials, 251–3; weather, 255.
Cows, dairy, longevity of, 49–56; average productive life, 49–50; economic value of longevity, 50–3; effect of culling, 53–4.

Das, P. K., the appetite of lambs grazing cobalt-deficient pasture, 112–18.
Davies, R. O., pasture productivity in Mid-Wales. Pt. I. Experimental methods of measurement, 203–17. Pt. II. Botanical changes in experimental plots, palatability and 'efficiency' of the swards, 264–70.

Edwards, E. E., the control of the tick (*Ixodes ricinus* L.) on grassland, 119–28.
El-Sokkary, A. M., *see* Sirry, I.

Grass, protein quality of, 31–40; determination of, 31 sqq.; composition of grass samples and diets fed to guinea-pigs, 33–4; protein quality of first and second cuts from permanent and temporary grass, 34–5, of cocksfoot and Italian ryegrass, 35–6.
Grassland, control of the tick *Ixodes ricinus* L. on (*see* under Tick).
Grassland production from veld in South Africa, 8–18; composition of veld herbage, 8–9; fertilizer treatments, 10–11; grazing methods, 9–10; live-weight gains and financial returns, 11–15, 16–17; rates of stocking, 11.

Hall, T. D., production from grassland in South Africa: fertilizer treatments and livestock gains on veld, 8–18.
Halliday, D. J., *see* Templeman, W. G.
Hallsworth, E. G., the composition of some coastal pastures in New South Wales and its relationship to milk production. Pt. I. Composition of pastures, 60–72. Pt. II. Relationship of pasture composition to milk production, 73–80.
Hancock, John, grazing habits of dairy cows in New Zealand, 249–63.
Haskell, Gordon, studies with sweet corn. II, Sowing dates and plant characters, 1–7.
Hassan, H. A., *see* Sirry, I.
Hevea, the Prang Besar (Malaya) experiments in the selection and propagation of, 105–11; budding and budded rubbers, 105, 110, 111; clones, 105, 108, 109, 112; isolation, 106–7; isolation gardens, 106; planting out, 109–10; seed gardens: constitution of, 109, lay-out, 107, yields from, 107, 109; seedlings and test tapping: nursery tests, 110, *v.* buddings, 109; vegetative propagation, 106.
Horn, A., correlation between constitution and milk production of dairy cows, 57–9.
Hunter, A. W. S., breeding for disease-resistance in Canada. Pt. III. Horticultural crops and tobacco, 218–26.

Lambs, appetite of, grazing cobalt-deficient pasture, 112–18.
Lewis, A. H., *see* Procter, J.
Leys cut for hay, the productivity of, 281–8; experimental details, 281–3; herbage: protein-content, 285–6, total growth of, 283–5, utilization of, 286–7.
Lloyd, J. R., *see* Davies, R. O.

Maher, Colin, soil conservation in Kenya Colony. Pt. I, 137–49, Pt. II, 233–48.
Meredith, D., *see* Hall, T. D.
Milk, production of dairy cows, 49–56, 57–9; of Egyptian sheep, 163–8.
Miller, T. B., *see* Barnett, A. J. G.
Milton, W. E. J., *see* Davies, R. O.
Mineral deficiencies in arable crops in Hereford and Somerset, 41–8; climate and soils,

42–3; methods, 41–2; results and conclusions, 43–7.
Murray, D. B., photo-periodism in rice in Trinidad with reference to a second crop, 271–5.

Oil-palms in Malaya, research on, 276–9; agronomic, 276–9; manurial experiments, 276–7; replanting, 277; selection and breeding work, 278–9; stem-rot, 277.
Oldaker, C. E. W., *see* Bald, J. G.

Pasture, cobalt-deficient, appetite of lambs on, 112–18; faecal excretion, 113–14, 115–16; grazing experiment in 1946, 113–14, in 1947, 114–16; lamb live-weights, 114, 116.
Pasture grasses in southern Africa, 90–2.
Pasture productivity in mid-Wales. Pt. I. Experimental methods of measurement, 203–17: Lay-out of experiment, 204–6; methods of measuring productivity, 206–7; results in first grazing season, 207–9, in three grazing seasons combined, 209–15. Pt. II. Botanical changes, 264–5, 266. Palatability and efficiency of reseeded grass and permanent pasture, 265–9.
Pastures, coastal, in N.S. Wales. Pt. I. Composition of pastures, 60–72. Botanical composition, 61; chemical composition, 62–6, compared with other pastures, 69–76; climate and soil, 60–1; correlation between protein and other constitutents, 66–7; sampling procedure, 62, 67; statistical considerations, 66–7, 72. Pt. II. Relation of pasture composition to milk production, 73–80. Average milk production and protein intake, 74–6; intake of other nutrients, 79; quantities of nutrients consumed, 76–9.
Pearsall, W. H., the investigation of wet soils and its agricultural implications, 289–98.
Plant, William, a survey of mineral deficiencies on arable land in two English counties, 41–8.
Plant-growth regulators, field experiments in selective weed-control by. Pt. I, 19–30. Investigations on cereal crops at Jealott's Hill in 1943–5, 21–6; at outside centres, 26–8. Pt. II. Effect on cereal crops, 169–76. Abnormalities due to plant-growth regulators, 172–4; comparison of M.C.P.A. with D.C.P.A., 175–6; effect on germination, 174–5; on yields, 169–72.
Pole Evans, I. B., the possibilities of beef production in southern Africa, 81–94.
Potato clones, testing and maintenance of, 95–104; differences between clones of the same maturity, 100–3; maturity differences and yield, 97–100; use of clones for certified seed, 103–4.
Procter, J., an experiment on the productivity of leys cut for hay, 281–8.

Rendel, J. M., some aspects of longevity in dairy cows, 49–56.
Rice in Malaya, research on, 227–32; agronomic, 228–30; main crops in Malaya, 227; padi test plots and experiment stations, 229; selection and breeding work, 230–2.
Rice, photo-periodism of, in Trinidad, 270–5; experimental work in 1947, 271–3; in 1948, 273–5; growth and yield of Joya rice in 1947–9, 272–3, in 1948 (second crop), 274–5.
Robertson, A., *see* Rendel, J. M.

Sheep, Egyptian, milk production of, 163–8; Ausimi and Rahmani breeds, 163 sqq.; milk yields, 164–6; mixed milk, analysis of, 164, 166–7.
Silo tower, preliminary experiments with a small-scale, 129–36; description and working of tower, 129–31; effluents: collection, transport, and analyses of, 131–5.
Singh, Mukhtar, confounding in split-plot designs with restricted randomization of sub-plot treatments, 190–202.
Sirry, I., milk production of Egyptian sheep, 163–8.
Soil conservation in Kenya Colony. Pt. I. Rainfall, 137–8; soils, 138–9; soil structure, 139 sqq., preservation or improvement of, 145–9; soil-conservation methods, 143–4. Pt. II. Soil-conservation in arable areas, 233–6; in plantation areas: coffee, 239–41, pyrethrum, 241–2, sisal, 238–9, tea, 236–7, wattle, 237–8; organization, &c., in the European areas, 242–4; present position and outlook, 244–7.
Soils, wet, investigation of, 289–98; *Aki-ochi* on degraded soils in Japan, 296–7; field tests, 290–1; nitrogen conversion, 294–5; nitrogen fertilizers, 295–6; swamp soils and rice growing, 295; waterlogging, 292–4.
Split-plot designs, confounding in, 190–202; construction of experiments and structure of their analysis, 191–4; examples of experiments in 1946 and 1947, 194–201.
Stewart, James, *see* Das, P. K.
Sweet corn (maize), studies with, 1–7; effects of sowing time (in England): on ear-characters and yield, 4–5, 6; flowering time and maturity, 1–4; plant height and tiller number, 5–7.

Templeman, W. G., field experiments in selective weed control by plant-growth regulators. I. Weed control in cereal crops, 19–30. II. The effect of plant-growth regulators upon cereal crops, 169–76.
Thomas, Brynmor, the protein quality of grass as determined by the method of Osborne and Mendel, 31–40.
Tick (*Ixodes ricinus* L.), control of, on grassland, 119–28; experimental area and incidence of red-water fever and nymphal ticks, 119–20; field control trials, 120–2; results, 122–7.

Watson, D. J., inflammability of cereal crops in relation to water-content, 150–62.
White, F. H., *see* Hunter, A. W. S.
Wilshaw, R. G. H., agronomic and breeding research on rice, oil-palms, and cacao in Malaya. Pt. I. Rice, 227–32. Pt. II. Oil-palms and cacao, 276–80.

AGRONOMY JOURNAL

VOL. 42, No. 10

CONTENTS

OCTOBER 1950

Plant Studies with Radioactive Sodium, by CHESTER D. LEONARD and STEPHEN J. TOTH. The effect of Cropping Systems and Soil Treatment on the Water-stable Aggregates in a Claypan Soil in Southeastern Kansas, by DAVID D. NEHER. The Estimation of Oil Percentage in Safflower Seed and the Association of Oil Percentage with Hull and Nitrogen Percentages, Seed Size, and Degree of Spininess of the Plant, by C. E. CLAASEN, W. G. EKDAHL, and G. M. SEVERSON. Reaction of Wheat Varieties with Known Genes for resistance to Races of Bunt, *Tilletia caries* and *T. foetida*, by F. N. BRIGGS and C. S. HOLTON. A Comparison of Cage and Mower Strip Methods with Grazing Results in Determining Production of Dairy Pastures, by R. E. WAGNER, M. A. HEIN, J. B. SHEPHERD, and R. E. ELY. The Use of Soft Resin Content for Evaluating Hops, *Humulus lupulus* L., by K. R. KELLER, D. E. BULLIS, and R. A. MAGEE. The Differential Response of Two Soil Associations to Rock Phosphate, by R. S. SMITH. Disease Reaction and Agronomic Qualities of Oats Selections from a Columbia×Victoria-Richland Cross, by J. M. POEHLMAN and C. H. KINGSOLVER. The Effect of Selection for Combining Ability Within Segregating Lines of Corn, by JOHN H. LONNQUIST. A Method of Adjustment for Calculating Comparable Yields in Variety Tests, by R. E. PATTERSON. The Influence of Acid-forming and Neutralized Fertilizers on the Soil Reaction and Nutrient Level in the Irish Potato Row During the Growing Season, by E. M. DUNTON, JR., F. W. BELL, and M. E. TAYLOR. The Use of Agronomists in Time of National Emergency, by C. L. W. SWANSON, WM. A. ALBRECHT, W. H. LEONARD, J. B. PETERSON, and S. C. VANDECAVEYE.

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